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A laboratory lysimeter for pesticide transport with controlled boundary conditions

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Abstract

The widespread use of various pesticides in agriculture is resulting in growing concern about contamination of soil, water and wider environment. This paper describes a laboratory lysimeter facility that allows undisturbed soil columns to be used with controlled boundary conditions to quantify the transport of pesticides through the soil. The Br⁻ breakthrough results to date indicated that the laboratory lysimeters are suitable for pesticide transport studies through the soils over a range of soil types, environmental conditions and hydraulic or soil water conditions and can provide valuable data to aid in improved transport risk assessment.

Key Words

Pesticide transport, undisturbed soil column, breakthrough curve

Introduction

Water is a solvent capable of carrying significant quantities of dissolved pesticides and other agro-chemicals. Pesticides can be found in surface and groundwaters due to runoff and/or leaching (Goss 1992; Holvoet *et al.* 2007). The transport of pesticides through soil is a function of water movement mechanisms, the chemical properties of the soil and the properties of the pesticide itself (degradation rate and adsorption / desorption characteristics). The physics of soil water and solute movement can be used to determine the fate of pesticide compounds, although the physico-chemical interactions of the solute with the soil particles will vary depending on the nature of the solute as well as the solid (Leeds-Harrison 1995). In many pesticide studies these interactions are characterized by pesticide specific sorption isotherms that are related to soil properties such as organic carbon content, soil texture, pH and cation exchange capacity (Gao *et al.* 1998; Wauchope *et al.* 2002; Picton and Farenhorst 2004). Several studies have been published that used either disturbed or undisturbed soil columns (Köhne *et al.* 2006; Dousset *et al.* 2007) to understand the transport of a given pesticide in the soil system. When disturbed soil is used, the focus of the study is on the role of soil constituents and pesticide interaction while undisturbed soil permits consideration of the role of pore structures on transport kinetics. Studying undisturbed soil also permits evaluation of the role of soil water status on transport, but systematically controlling soil water status can be quite difficult.

Pesticide transport studies can be conducted in the field (Højber *et al.* 2005), in field lysimeters (Winton and Weber 1996) or in laboratory lysimeters (Köhne *et al.* 2006). Field scale studies have the advantage of revealing the consequences of interaction with the natural climate and environment, but are complicated by the fact that it becomes difficult to control the consequences of variable temperature effects on degradation rates. Studies to understand pesticide kinetics in soils require laboratory experiments in order to have a controlled environment as one of the variables / treatments. This paper describes a laboratory lysimeter facility that was designed to permit: (i) undisturbed soil columns to be studied; (ii) controlled boundary conditions to be used to evaluate the role of different pores sizes in pesticide transport ; and (iii) control of soil water status to evaluate which soil pores function in pesticide transport under various conditions. Preliminary evaluation of the system was undertaken with a Bromide tracer to determine the main physical transport characteristics of selected soils before undertaking pesticide transport studies.

Methods

Lysimeter design

The lysimeter system (Figure 1) was designed to enable examination of saturated and unsaturated transport of agrochemicals through undisturbed soils. The system is operated in an air conditioned lab (ambient temperature of 20 °C ± 2). At its centre is a soil column 10 cm i.d. x 20 cm long. This is contained between thin layers of sand held in place by mesh and clamped by end-plates and steel rods. The sample is prepared

such that there is a clean surface top and bottom that are tightly held against the sand to ensure hydraulic continuity throughout the system. The end caps are sealed in place using molten paraffin wax. Above the soil column are two reservoirs, one containing a Br⁻ solution and one containing the agro-chemical of interest for the study. Below the soil column is an effluent trap, a pressure regulator and a vacuum pump. Alternatively a peristaltic pump can be installed above the soil column. When using pressure heads to drive transport, the system can be set up to permit transport with small hydraulic heads by gravity or with larger heads by the vacuum pump. Alternatively transport can be forced at a constant flux by using the peristaltic pump. A range of soil water status conditions can thus be established ranging from a wetting cycle, through saturated flow to a drying cycle. For evaluating a particular agrochemical, the soil column is first saturated with a Br⁻ solution at known constant hydraulic head. Once the system is in equilibrium, or at the desired condition, the agrochemical is introduced by changing the source of transporting solution. The agrochemical can be injected by either a step or pulse method.

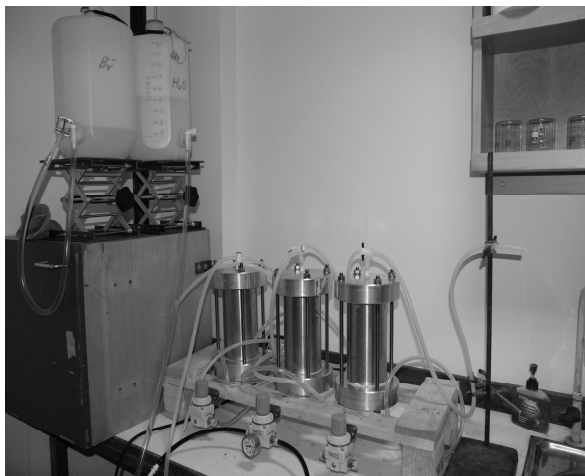
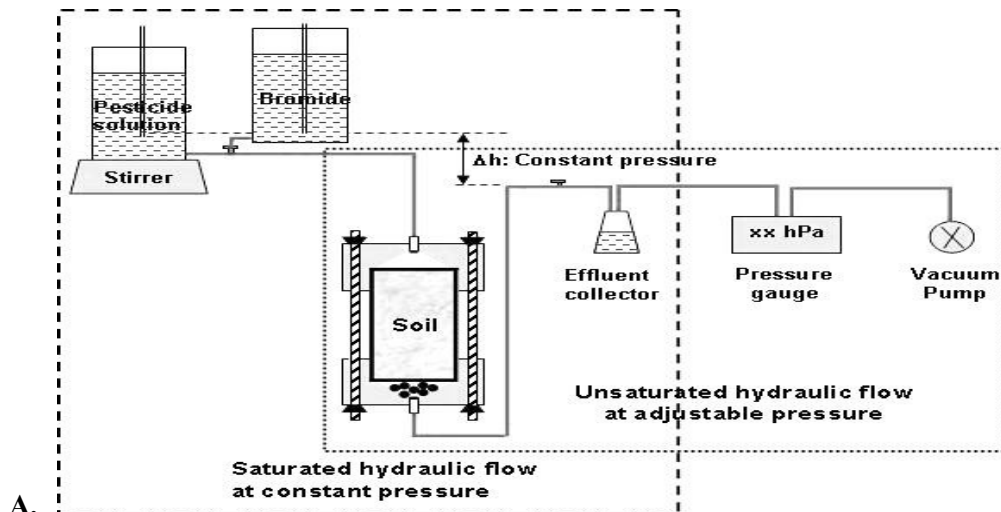


Figure 1. Soil column apparatus used in transport experiment: A: Schematic. B: Photograph

Soil sampling

Soils are sampled by driving stainless steel soil columns (10 cm i.d., 20 cm long) into the soil. For very stony soils, a plinth of soil can be isolated, the steel ring placed around it and the cavity filled with molten paraffin wax. Once filled with soil, the columns are excavated and sealed in air- and water-tight plastic bags. The ends of the columns are supported to ensure there is as little transport disturbance as possible.

For the preliminary evaluation of the system, two soils (Elton (E) and Clonroche (CL) series) that are typical of arable soils in Ireland were sampled. In addition to the undisturbed soil columns, samples were taken in triplicate for bulk densities at 0-10 cm and 10-20 cm depths, and a composite disturbed soil sample (0-15 cm) was taken for physico-chemical analysis. The loose soil was air-dried and ground to pass through a 2 mm sieve before analysis. Soil columns were stored in the dark at 4°C until use.

Results

The soils differed in bulk density, but other properties were very similar, reflecting their typical use as arable soils (Table 1).

Table 1. Physio-chemical characteristics of soils used.

Depth (cm)	Soil type	clay	silt	sand	pH (in CaCl ₂)	Cation Exchange Capacity (Cmol/kg)	Bulk density (g/cm ³)
		(%)					
0-10	E	29	65	6	6.3	23.4	1.15
10-20							1.26
0-10	CL	30	68	2	6.3	19.9	1.03
10-20							1.00

We saw that the soils had very high hydraulic conductivity, which reflected the loose, aggregated topsoil structure that contained many large pores (Figure 2). The Br⁻ breakthrough provides a useful comparison for agrochemicals. If the breakthrough of a pesticide is slower than Br⁻, then there is potentially a significant soil interaction and retention of the active ingredient.

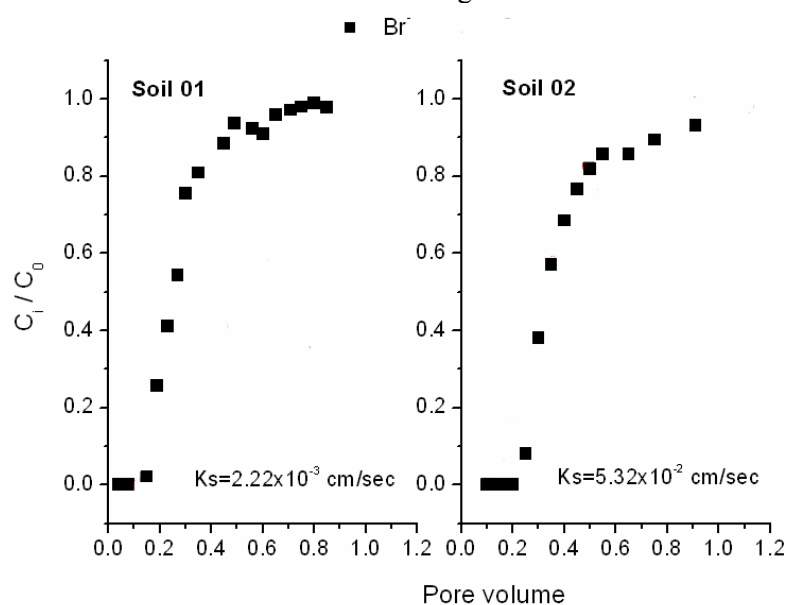


Figure 2. Br⁻ breakthrough curves for two Irish soils under saturated conditions with step input of Br⁻.

Preliminary work with the system indicated that it would provide valuable data on agrochemical transport through undisturbed soils over a range of soil types (unlimited as even stony soils can be sampled), environmental conditions (from very low temperatures to tropical conditions as controlled by constant temperature laboratory settings) and hydraulic or soil water status conditions (wetting, saturated, drying, step input, pulse input, constant flow).

Prior to full experimentation with the system, work will be conducted on the effects of pesticide degradation rates within the system to evaluate the role of time in data analysis (Blumhorst 1996). We expect quite different results between soils and chemicals. For example mobility studies on chlorothalonil suggest that it is immobile or moderately mobile in soils due to its high sorption (Ngan *et al.* 2005). We will be able to evaluate whether boundary conditions and soil water status influence its transport and fate.

Conclusion

The Br⁻ breakthrough results to date indicate that the laboratory lysimeter system will be suitable for pesticide transport studies and will provide valuable data to aid in improved transport risk assessment.

References

Blumhorst MR (1996) Experimental parameters used to study pesticide degradation in soil. *Weed Technology* **10**, 156-216.

- Dousset S, Thevenot M, Pot V, Šimunek J, Andreux F (2007) Evaluating equilibrium and non-equilibrium transport of bromide and isoproturon in disturbed and undisturbed soil columns. *Journal of Contaminant Hydrology* **94**, 261-276.
- Gao JP, Maguhn J, Spitzauer P, Kettrup A (1998) Sorption of pesticides in the sediment of the Teufelsweiher Pond (Southern Germany). I: Equilibrium assessments, effect of organic carbon content and pH. *Water Research* **32**, 1662-1672.
- Goss DW (1992) Screening procedure for soils and pesticides for potential water quality impact. *Weed Technology* **6**, 701-708.
- Holvoet KMA, Seuntjens P, Vanrolleghem PA (2007) Monitoring and modelling pesticide fate in surface waters at the catchment scale. *Ecological Modelling* **209**, 53-64.
- Köhne JM, Köhne S, Šimunek J (2006) Multi-process herbicide transport in structured soil columns: Experiments and model analysis. *Journal of Contaminant Hydrology* **85**, 1-32.
- Højberg AL, Engesgaard P, Bjerg PL (2005) Pesticide transport in an aerobic aquifer with variable pH- Modelling of a field scale injection experiment. *Journal of Contaminant Hydrology* **78**, 231-255.
- Leeds – Harrison PB (1995) The movement of water and solutes to surface and groundwaters. In 'Pesticide Movement to Water' (Ed. A Walker *et al.*) Monograph No 62, pp.3-12. (British Crop Protection Council: Surrey, UK).
- Ngan CK, Cheah UB, Abdullah WYW, Lim KP, Ismail BS (2005). Fate of chlorothalonil, chlorpyrifos and profenofos in a vegetable farm in Cameron Highlands, Malaysia. *Water, Air, & Soil Pollution: Focus* **5**, 125-136.
- Picton P, Farenhorst A (2004) Factors influencing 2,4 – D sorption and mineralization in soil. *Journal of Environmental Science and Health, Part B- Pesticides, Food Contaminants, and Agricultural Wastes* **B39**, 367-379.
- Wauchope RD, Yeh S, Linders JBHJ, Kloskowski R, Tanaka K, Rubin B, Katayama A, Kördel W, Gerstl Z, Lane M, Unsworth B (2002) Review Pesticide soil sorption parameters: theory, measurement, uses, limitations and reliability. *Pest management Science* **58**, 419-445.
- Winton K, Weber JB (1996) A review of field lysimeter studies to describe the environmental fate of pesticides. *Weed Technology* **10**, 202-209.

Effect of grass cover on pesticides transport through soil: Undisturbed column studies and field experiments in the Morcille watershed (Beaujolais)

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Abstract

The objective of this study is to elucidate the role of grass cover on the leaching of diuron, tebuconazole and procymidone through undisturbed soil columns of a bare vineyard soil and a grass-covered soil. Run-off events containing a mixture of the three pesticides were simulated. Lower quantities of the three pesticides leached through the buffer zone soil (from 6.7 to 24.3% of the initial amount in runoff) than the bare soil (from 8.0 to 55.1%), in correspondence with their adsorption coefficients, which were from 4 to 6 times higher in the buffer zone than in the bare soil. Diuron was recovered in higher amounts in leachates (from 14.6 to 32.2%) than tebuconazole (from 6.7 to 8.0%), in agreement with their adsorption coefficients. However, despite having an adsorption coefficient similar to that of diuron, more procymidone ($K_d = 4.2\text{--}14.1$ L/kg) was recovered in the leachates (from 24.3 to 55.1%). This may be due to facilitated transport of procymidone by dissolved organic matter. Thus even in this very permeable soil, higher organic matter contents associated with grass-cover reduce the amounts of pesticide leaching and limit the risk of ground water contamination by the pesticides. The results are in agreement with field observations.

Key Words

Buffer zone, vineyard soil, leaching, herbicide, fungicide, commercial formulation.

Introduction

Many recent studies have reported the presence of pesticide residues, at concentrations higher than the European Quality Standards, in surface- or ground-waters near several vineyards. Consequently, agricultural institutions advise wine producers to use alternative practices to chemical weeding, and to reduce pesticide transfer such as grass-covered inter-row vineyard or buffer zones. Several studies have shown that the amount of pesticide in the run-off from vegetated buffer zones is lower than the amount entering the zone (Patty *et al.* 1997; Watanabe and Grismer 2001) due to processes of retention and/or infiltration within the vegetated zone (Kloppel *et al.* 1997; Mersie *et al.* 2003). However, reducing the quantities of pesticides found in surface waters by promoting their infiltration in buffer strips may threaten shallow water tables or even groundwater with pesticide contamination. Very few studies have been conducted on the quantities of pesticides leached from vegetated soils. The Cemagref of Lyon established an experimental site in 2004, in order to assess the efficiency of vegetated buffer zone to reduce pesticide run-off, and the subsequent pesticide infiltration through the buffer zone (Boivin *et al.* 2007). Their results demonstrated a global reduction in pesticide concentrations leached to a 50 cm soil depth relative to the initial concentration of the incoming runoff. Their attempts to quantify the reduction, however, were hampered by the difficulty in making reliable mass balances in the field.

Thus, the objectives of this study were (i) to implement an experiment permitting the comparison of pesticide leaching in a buffer zone soil and a bare cultivated soil, that results in better mass balance control; (ii) to better assess the role of grass cover on water infiltration, and leaching or adsorption of one herbicide (diuron) and two fungicides (tebuconazole and procymidone), through a Beaujolais vineyard soil during run-off events; and (iii) to compare the possible release of pesticides from soils after subsequent run-off events. The results of our work were compared to those obtained at the experimental site in St Joseph by Boivin *et al.* (2007).

Material and methods

Chemicals

Diuron, two of its metabolites (DCPMU and DCPU), tebuconazole, and procymidone were supplied from Cluzeau (Sainte-Foy-La-Grande, France) with > 99% certified purity. Commercial pesticide formulations were used: Canyon (diuron), Folicur EW (tebuconazole) and Sumisclex (procymidone).

Soil sampling and column set-up

The experimental site monitored by Cemagref of Lyon (69, France) is located in the Beaujolais region near St Joseph (Rhône, France). It consists of an experimental plot (25.2 m²) on a 25% slope laid out on a vegetated buffer zone (an old meadow buffer zone), located between a chemically-treated hillside vineyard and the Morcille stream. The soil is a sandy loam (luvic cambisol, FAO 1998). Undisturbed soil columns (15.5 cm Ø x 20 cm length) were carved and excavated by hand, according to the method described by Dousset *et al.* (2007), in March 2007, before the fields were treated with pesticide. Six columns were prepared: 3 from the bare soil field (B_{L1}, B_{L2}, B_{L3}) and 3 from the buffer-zone field (BZ_{L1}, BZ_{L2}, BZ_{L3}).

Water inflows and experimental set-up

Three artificial inflows (simulating vineyard runoff events) were replicated at three different times (T₀, T₁₄ and T₂₈ days, respectively) on the soil surface of each column. The first water inflow (T₀) contained a homogeneous mixture of 5 mg/L bromide (Br⁻) and, 100 µg/L diuron, procymidone and tebuconazole, simulating contaminated runoff after a rainfall event. Br⁻ was added as a water tracer. A 3.6 L volume of solution was applied onto the surface of each column (176.6 cm²) equivalent to the 4800 L water volume applied to the experimental vegetated buffer zone (25.2 m²) in the field experiment monitored by Boivin *et al.* (2007). This simulated runoff corresponds to a < 2-yr rain event frequency (Lacas 2005). The Br⁻-pesticide solution was applied at a constant flow rate of 10.2 cm/h using a peristaltic pump. Two additional water inflow additions, consisting only of 3.6 L of water, were applied to the columns fourteen (T₁₄) and twenty eight days (T₂₈) after the pesticide application in order to assess potential pesticide release from the soil.

Leachate collection and analyses

Column effluent was collected at 6-min intervals in 250-mL glass bottles. Each leachate sample from the first water inflow (T₀) was kept for analysis. When collecting effluent from the second (T₁₄) and third (T₂₈) water inflow events, three consecutive samples were mixed; so that, column effluent was essentially collected at 18-min intervals. Pesticide residues contained in the leachates were concentrated by solid-phase extraction with an LC-18 bonded silica cartridge (12 mL, Supelclean, Supelco). Pesticide recoveries were 95.8% for diuron, 95.1% for DCPMU, 88.8% for DCPU, 82.6% for procymidone and 55.6% for tebuconazole. All sample concentrations were corrected based on these recovery values. Pesticides and bromide analyses were performed with a Waters HPLC as described by Dousset *et al.* (2007). UV detection was performed at 249 nm for diuron, DCPMU and DCPU, 220 nm for tebuconazole and 203 nm for procymidone and 200 nm for bromide. Detection limits were 1 µg/L for diuron, DCPMU, DCPU, and tebuconazole, 2 µg/L for procymidone and, 0.25 mg/L for Br⁻.

Soil characterization

The mean porosities were 0.41 ± 0.04 cm³/cm³ for the bare soil and 0.49 ± 0.02 cm³/cm³ for the grass-covered soil. At the end of the monitoring period, the columns were sectioned into 5 layers, air-dried, weighed, and sieved to 2 mm. All analyses (Table 1) were carried out at INRA-Arras, France.

Table 1. Main characteristics of the soils.

Depth > 2 mm fraction (cm)	Sand (-----)(%)-----)	Silt	Clay	OC	pH _{H2O}	CEC (cmol/kg)	
							Bare Vineyard soil
0-2.5	4.5 ± 1.8	85.2 ± 6.6	9.5 ± 4.1	5.3 ± 2.5	0.8 ± 0.2	5.3 ± 0.3	4.1 ± 1.2
2.5-5	4.1 ± 0.7	79.2 ± 6.9	13.2 ± 4.3	7.7 ± 2.6	0.8 ± 0.2	5.0 ± 0.2	5.1 ± 1.9
5-10	9.0 ± 1.4	75.8 ± 3.5	15.2 ± 2.1	9.0 ± 1.5	0.8 ± 0.1	4.7 ± 0.4	6.2 ± 0.9
10-15	8.2 ± 1.4	74.5 ± 2.1	15.8 ± 1.3	9.7 ± 1.0	0.7 ± 0.1	4.8 ± 0.7	6.0 ± 1.4
15-20	4.6 ± 3.2	76.1 ± 4.4	14.6 ± 2.8	9.2 ± 1.7	0.7 ± 0.2	4.6 ± 0.4	6.5 ± 1.3
Buffer zone							
0-2.5	1.3 ± 0.7	63.5 ± 10.2	20.4 ± 5.6	14.5 ± 4.0	4.0 ± 2.1	5.7 ± 0.3	10.0 ± 1.3
2.5-5	2.6 ± 1.0	63.2 ± 4.0	21.7 ± 2.9	14.8 ± 1.7	3.5 ± 1.1	5.5 ± 0.4	11.5 ± 2.5
5-10	5.5 ± 4.1	68.1 ± 6.8	18.1 ± 3.1	12.2 ± 1.6	2.2 ± 0.5	5.2 ± 0.1	15.6 ± 8.8
10-15	9.5 ± 1.2	69.9 ± 3.5	18.6 ± 2.3	11.6 ± 1.5	1.4 ± 0.4	5.2 ± 0.3	10.3 ± 4.6
15-20	5.3 ± 4.8	70.9 ± 8.8	17.7 ± 5.9	11.4 ± 2.9	1.3 ± 0.3	5.2 ± 0.1	8.8 ± 1.3

Batch adsorption coefficient measurement

Adsorption of the three commercial pesticide formulations (Canyon, Sumisclex and Folicur EW) to the soils was measured using a batch equilibrium method. Each sample consisted of 2 g of dried soil (0-5 cm depth) mixed with 10 mL pesticide solution, in concentrations ranging from 1 to 10 mg/L, in a 50-ml Teflon centrifuge tube. Sorption isotherms were obtained following the procedure outlined by Dousset *et al.* (2007) and were described using linear isotherms (K_d).

Results

Adsorption isotherms of diuron, tebuconazole and procymidone

The adsorption coefficients of the three soils are higher in the buffer zone soil ($K_d = 12.0-42.2$ L/kg) than in the bare soil ($K_d = 2.2-10.5$ L/kg) (Table 2), in relation with their organic carbon contents at the 0-5 cm depth (buffer zone: 3.8%, and bare soil: 0.8%) (Table 1). For the grass-cover and the bare soils, tebuconazole is adsorbed in greater amounts ($K_d = 10.5-42.2$ L/kg) than procymidone ($K_d = 4.2-14.1$ L/kg) and diuron ($K_d = 2.2-12.0$ L/kg). Similar diuron adsorption values were obtained by Lacas (2005) with bare soil from the 0-20 cm depth ($K_d = 4.6$ L/kg) and buffer zone soil from the 0-5 cm depth ($K_d = 14.2$ L/kg).

Table 2. Distribution coefficients (K_d) of the 3 pesticides on the bare (B) and the buffer zone (BZ) soils.

Pesticide	Soil	K_d (L/kg)	r^2
Diuron	B	2.20	0.982
	BZ	12.0	0.979
Tebuconazole	B	10.5	0.979
	BZ	42.2	0.983
Procymidone	B	4.2	0.996
	BZ	14.1	0.995

Water infiltration and bromide recovered

The water flow was relatively homogeneous between the triplicates of each soil treatment; the eluted water flow rates were quite similar and constant for both the bare (83 ± 3 mm/h) and the buffer zone (80 ± 0.3 mm/h) soils throughout the three flow events. The buffer zone flow rate is slightly lower than the saturation hydraulic conductivity of 125 mm/h at 15 cm depth reported by Lacas (2005). After the three water inflows, bromide was eluted in greater amounts in the percolates of the bare soil ($74.0 \pm 1.0\%$) than in those of the buffer zone soil ($59.9 \pm 1.2\%$) (Table 3). At the St Joseph experimental site, Boivin *et al.* (2007) estimated a bromide leaching rate of 90% of the total amount added in the inflow, at the 50 cm soil depth, which is relatively similar to our results, especially when considering the uncertainty linked to their results (extrapolation of the results from 4 x 2 lysimeters (0.125 m² each) to the total buffer strip (25 m²)).

Table 3. Recovery percentages of initial amounts of bromide and pesticides for the 3 water inflows.

	Eluted water volume (L)	Bromide	Diuron	DCPMU	DCPU	Tebuconazole	Procymidone
B _{L1}	9.7	73.1	31.5	8.9	0.1	3.9	90.1
B _{L2}	9.6	75.1	22.7	7.0	0.1	1.3	24.3
B _{L3}	9.4	73.9	42.5	7.1	2.9	18.7	50.8
Mean \pm SD	9.6 \pm 0.2	74.0 \pm 1.0	32.2 \pm 9.9	7.6 \pm 1.1	1.0 \pm 1.6	8.0 \pm 9.4	55.1 \pm 33.1
BZ _{L1}	10.2	60.7	12.2	0.2	0.1	4.6	18.2
BZ _{L2}	10.3	58.5	10.3	0.1	0.0	3.7	17.5
BZ _{L3}	10.2	60.5	21.5	0.2	0.2	11.9	37.2
Mean \pm SD	10.2 \pm 0.1	59.9 \pm 1.2	14.6 \pm 6.0	0.2 \pm 0.1	0.1 \pm 0.1	6.7 \pm 4.5	24.3 \pm 11.1

Pesticides recovered

The quantities of pesticide leached at the end of the three simulations were greater in the bare soil leachates (8.0% to 55.1% of applied) than in those of the buffer zone soil (6.7% to 24.3%) (Table 3). For both soils, the amounts of the pesticides recovered in the leachates varied somewhat between triplicates of a given soil treatment despite having similar pore volumes, coarse fraction contents, and Br⁻ recoveries. Diuron metabolites (DCPMU and DCPU) were recovered in greater amounts in the bare soil leachates (7.6 and 1.0% of the initial amount of parent molecules, respectively) than in those of the buffer zone (0.2 and 0.1%). Of the total amounts of pesticide leached in the three simulations, diuron was recovered in greater amounts (32.2% and 14.6% of the applied amount) than tebuconazole (8.0% and 6.7%) in the percolates of bare and buffer zone soils (Table 3), in correspondence with their respective adsorption coefficients ($K_d = 2.2-12.0$ L/kg and $10.5-42.2$ L/kg). However, procymidone was measured in greater amounts in the leachates (24.3 to

55.1%) than either diuron or tebuconazole, contrary to what would be expected based on its adsorption coefficient ($(K_d = 4.2-14.1 \text{ L/kg})$ (Tables 2, 3). After the second and third runoff events (14 and 28 days after the first inflow event), low to significant amounts of pesticide were released to the soil solution (11.3-50.4% of the total leached amounts, or, 1.5 to 26.4% of the applied pesticide). The buffer zone soil released less pesticide to the soil solution (0.9 to 12% of the applied amounts) than the bare soil (1.5 to 26.4%) (Table 4) in agreement with their adsorption coefficients. Furthermore, diuron was detected in greater amounts (4.4 to 11.5% of applied) than tebuconazole (0.9 to 1.5%) in the leachates, also in agreement with their respective adsorption coefficients (Table 2) and similar half-lives (Footprint, 2007-2008). Again, procymidone was released in greater amounts (12.0 to 26.4%) than either diuron or tebuconazole (Table 4).

Boivin *et al.* (2007) also found that more diuron (34%) than tebuconazole (31%) leached through the buffer zone at the St Joseph experimental site. Although their values are far higher than ours (8.5% for diuron and 0.8% for tebuconazole), the uncertainty associated with their results must be considered, as suggested for Br⁻.

Table 4. Recovery percentages of initial amounts bromide and pesticides for the (2nd+3rd) water inflows.

	Eluted water volume (l)	Bromide	Diuron	DCPMU	DCPU	Tebuconazole	Procymidone
B _{L1}	6.6	7.0	11.9	5.4	0.1	0.7	51.4
B _{L2}	6.5	8.5	12.9	4.6	0.1	0.6	11.1
B _{L3}	6.3	2.1	9.8	4.8	2.9	3.1	16.7
Mean ± SD	6.5 ± 0.1	5.9 ± 3.4	11.5 ± 1.6	4.9 ± 0.4	1.0 ± 1.6	1.5 ± 1.4	26.4 ± 21.8
BZ _{L1}	6.8	0.5	4.0	0.2	0.1	0.2	9.2
BZ _{L2}	6.8	3.6	3.2	0.1	0.0	0.5	9.4
BZ _{L3}	6.8	2.0	5.9	0.2	0.2	1.9	17.5
Mean ± SD	6.8 ± 0.0	2.0 ± 1.6	4.4 ± 1.4	0.2 ± 0.1	0.1 ± 0.1	0.9 ± 0.9	12.0 ± 4.7

Conclusion

More diuron than tebuconazole is recovered in the leachates in agreement with their adsorption coefficients. However, more procymidone than diuron was recovered in the leachates, despite their similar adsorption coefficients. This may be due to the facilitated transport of procymidone by dissolved organic matter. All three pesticides used in this study were eluted in lower amounts through the buffer zone than through the bare soil, in correspondence with their adsorption coefficients, which were from 4 to 6 times higher in the buffer zone than in the bare soil. Consequently, buffer zones not only reduce the risk of contamination of surface waters, but also do not appear to increase the risk of groundwater contamination by pesticides.

References

- Dousset S, Thévenot M, Pot V, Simunek J, Andreux F (2007) Evaluating equilibrium and non-equilibrium transport of bromide and isotopuron in disturbed and undisturbed soil columns. *Journal of Contaminated Hydrology* **94**, 261-276.
- Footprint 2007-2008. The FOOTPRINT Pesticide Properties Database. Database collated by the University of Hertfordshire as part of the EU-funded FOOTPRINT project (FP6-SSP-022704).
- Boivin A, Lacas JG, Carlier N, Margoum C, Gril JJ, Gouy V (2007) Pesticide leaching potential through the soil of a buffer strip in the river Morcille catchment (Beaujolais). In 'Environmental fate and ecological effects of pesticides, proceedings of the XIII Symposium Pesticide Chemistry, Piacenza, Italy' (Eds AAM Del Re, E Capri, G Fragoulis, M Trevisan) pp. 357-365.
- Kloppel H, Kördel W, Stein B (1997) Herbicide transport by surface runoff and herbicide retention in a filter strip - rainfall and runoff simulation studies. *Chemosphere* **35**, 129-141.
- Lacas JG (2005) Processus de dissipation des produits phytosanitaires dans les zones tampons enherbées. PhD, Université of Montpellier.
- Mersie W, Seybold CA, McNamee C, Lawson MA (2003) Abating endosulfan from runoff using vegetative filter strips: the importance of plant species and flow rate. *Agriculture Ecosystems and Environment* **97**, 215-223.
- Patty L, Réal B, Gril JJ (1997) The use of grassed buffer strips to remove pesticides, nitrate and soluble phosphorus compounds from runoff water. *Pesticide Science* **49**, 243-251.
- Watanabe H, Grismer ME (2001) Diazinon transport through inter-row vegetative filter strips: micro-ecosystem modeling. *Journal of Hydrology* **247**, 183-199.

Effect of Organic Fertilisation on the Nitrogen Leaching in the Grassland of the Czech Republic

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Abstract

Grasslands have an impact on the sustainability of nutrition in a country. In this paper the effects of organic fertilization on lysimetric water during a period of three years are presented. The experiment includes two fertiliser types – cow dung with dung-water and semi-liquid cattle manure with a graded load (0.9, 1.4 and 2.0 LU per hectare). The soil is sandy-loam, of the cambisol type, with semi-natural permanent grassland. We observed the content of N-NH₄⁺ and N-NO₃⁻ in the percolate. There was significantly higher leaching of ammonia and nitrate with the load of 2.0 LU and no statistically significant differences were found between the forms of organic manure applied. There were statistical differences between the estimated years. On the basis of the lysimetric water volume found and the concentrations of particular forms of inorganic nitrogen we reveal the annual washing-out of this nutrient from one hectare; it was 4.9 kg/ha for 0.9 LU, 4.8 kg/ha for 1.4 LU, and 6.1 kg/ha for 2.0 LU per year during the estimated period.

Key Words

Nitrite, manure, lysimeters, meadow.

Introduction

In the Czech Republic, there is 950 thousands ha of grasslands (23% of the agricultural area) and the most are situated in less favorable areas. The grazing and the cutting are traditional agriculture practices in these areas. But these managements can bring some environmental risks. With help of lysimeters we can claim which agriculture system is better from the nutrient leaching point of view. Lysimeters are excellent technical tools which are used for measuring of seepage water. For groundwater protection reasons the nutrient as well as pollutant content in the seepage water is from interest. The primary aim of lysimeter measurements on the base of analyses of percolated water is a monitoring of nutrient movement, especially nitrogen in soil. The least amount of mineral nutrients is fixed in soil solution by comparison with adsorbing complex and humus. Approximately 0.2 % of mineral nutrients are bound in soil solution.

Material and method

In the autumn of 2004 a small-plot trial on grassland with various types of management with animal fertilisation was established at Agriresearch, Rapotín, in the Czech Republic. The experiment is located on an east-facing slope 390 m above sea level and it belongs under the Hrubý Jeseník geomorphological division. The geomorphological subgrade is deeper diluvium of mica schist. The soil is sandy-loam, of the cambisol type (horizons Ao-Bv-B/C-C). The basic agrochemical soil proprieties are shown in Table 1.

Table 1. Agrochemical soil proprieties.

Diagnostic horizon	pH _{KCl}	CEC (mmol(p ⁺)/kg)	C _{org} Ratio (%)	C:N	P (mg/kg)	K (mg/kg)	Ca (mg/kg)	Mg (mg/kg)
Am	4.63	141	1.34	10.0	53	109	1799	124
Bv	4.60	130	0.73	9.5	78	62	1442	97
Bv/Cc	4.41	139	0.33	8.4	27	53	1753	131
Cc	4.44	151	0.19	10.5	29	45	1875	166

The mean annual precipitation in the locality is 693 mm, and the average annual temperature is 5.3°C; Table 2 shows data from the relevant season. In the locality there is semi-natural permanent grassland with these predominant species: *Dactylis glomerata*, *Poa pratensis*, *Lolium perenne*, *Taraxacum sect. Ruderalia*, and *Trifolium repens*.

Table 2 The precipitation and temperature in Rapotin during the season studied

Year	Month	I.	II.	III.	IV.	V.	VI.	VII.	VIII.	IX.	X.	XI.	XII.
2005	Precipitation (mm)	90.0	45.0	27.5	23.5	76.0	50.0	78.0	69.0	19.0	56	120	74.6
	Temperature (°C)	-1.3	-4.5	-0.7	8.9	12.7	15.6	18.3	15.7	13.4	4.9	3.1	-1.7
2006	Precipitation (mm)	36.1	63.7	62.7	62.2	63.5	78.1	52.0	110.0	7.2	24.5	59.1	68.2
	Temperature (°C)	-8.4	-2.6	-1.8	9.3	12.8	17.0	20.5	15.2	14.5	10.1	8.5	2.1
2007	Precipitation (mm)	68.5	49.7	40.0	4.7	66.3	49.2	69.2	68.2	54.2	34.1	67.9	37.2
	Temperature (°C)	3.2	2.7	5.0	9.7	11.4	17.7	18.9	17.7	11.0	7.2	1.6	-1.2

Plots with different pasture loads were arranged in a completely randomised block design with four replicate blocks. The plot size was 12.5 m². The plots were not grazed (grazing was simulated), but cut according to the grassland load, which was as follows:

- A – cow dung + dung-water with a load of 0.9 LU/ha
- B – cow dung + dung-water with a load of 1.4 LU/ha
- C – cow dung + dung-water with a load of 2.0 LU/ha
- D – slurry with a load of 0.9 LU/ha
- E – slurry with a load of 1.4 LU/ha
- F – slurry with a load of 2.0 LU/ha

(0.9 load unit LU corresponds to 54 kgN/ha and 2 cuts per year, 1.4 LU corresponds to 84 kgN/ha and 3 cuts per year, and 2.0 LU corresponds to 120 kgN/ha and 4 cuts per year)

The cow dung fertilisation was dosed in the autumn, dung-water after the first cut; half of the semi-liquid manure fertilisation was applied in the spring and the second half after the first cut. After every application we analysed the fertilisers and then, on the basis of the nitrogen contents, we counted the actual dosage. The lysimeters were at a depth of 0.4 m in an area of 0.25 m², in the four replications. In this paper we estimated the content of N-NH₄⁺ and N-NO₃⁻ in the percolate and the potential risk for the environment. The statistical analyses were performed with linear mixed models in the nlme and MASS packages in R software.

Results and discussion

The nitrate concentration in the environment is very variable during the year. Wessolek *et al.* (1994) describe nitrate leaching in sandy soils under different cultures. They show different nitrate concentrations in the root zone: in gardening soils 200-350 mg/L, in arable land 120-240 mg/L, and in soil under grassland without fertilisation < 40 mg/L. The values of nitrate concentration in the percolates were variable; from Figure 1 it can be seen that values over the pollution limit for drinking water (50 mg/L) were exceeded with the load of 0.9 LU only during the spring months.

The type of fertiliser had no influence on the nitrate leaching ($p = 0.0754$). The highest leaching was with the load of 2.0 LU (see Figure 2) and it was significantly higher ($p = 0.0089$) than the others. Gaisler (2003) presented nitrate concentrations from 4 to 15 mg/NO₃/L for the unfertilized grassland in the Czech Republic conditions in the same depth. There was found variability between the following years; in 2007 nitrate leaching was significantly ($p = 0.0001$) lower than in the other years, which corresponds to the lowest precipitation during this year (from March to December percolate was not present at a depth of 0.4 m).

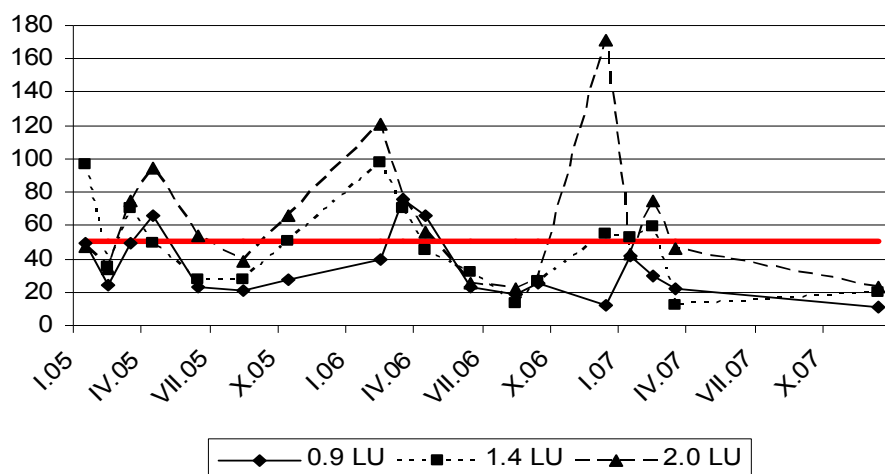


Figure 1. The nitrate concentrations in the percolate during the study period (mg/L)

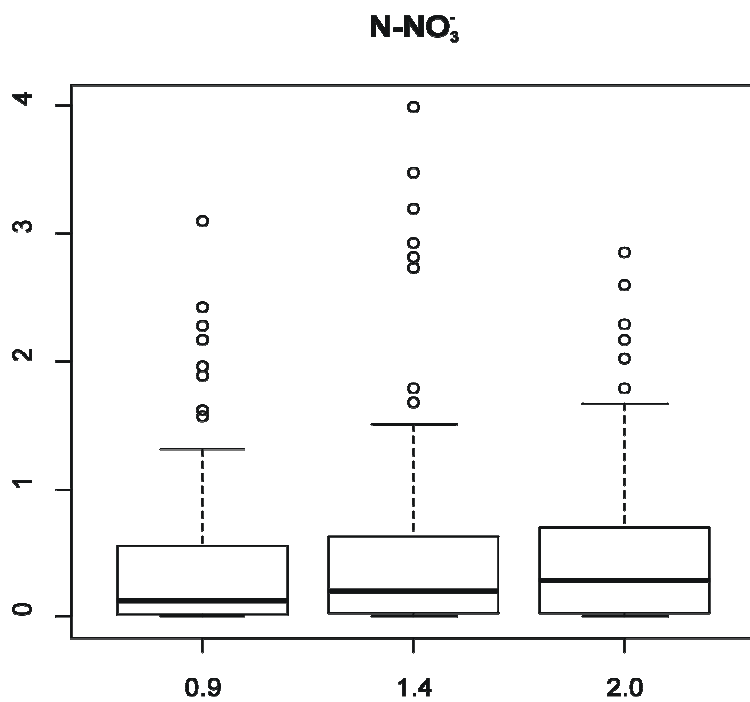


Figure 2. The leaching of nitrate nitrogen by the different load (mg/L).

The concentrations of ammonia were variable too. In Figure 3 can be seen that there was higher leaching of ammonia with the load of 2.0 LU ($p = 0.0599$). Compared to the following years, the leaching in 2005 was significantly higher ($p = 0.0442$) than in the other years; this could be caused by the high concentration of ammonia in precipitation during this year.

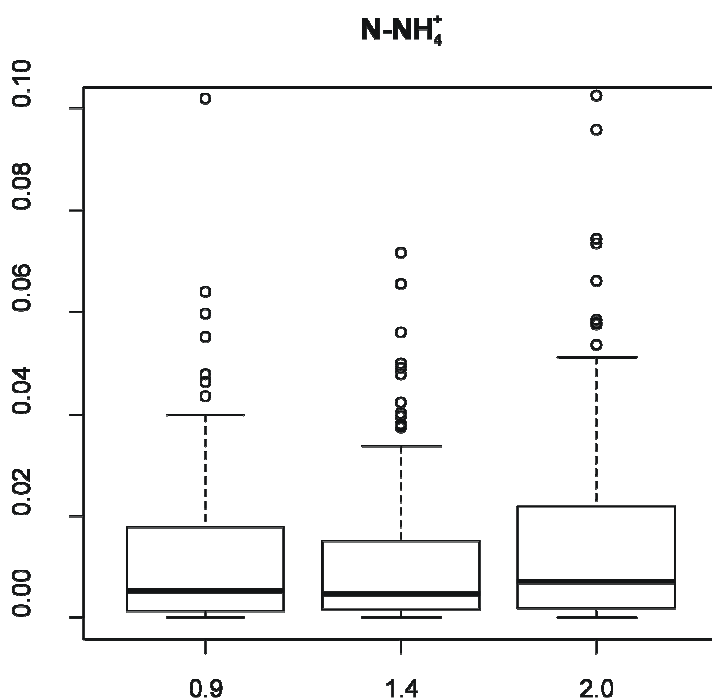


Figure 3. The leaching of ammonia nitrogen by the different load (mg/L).

We hold the summa of mineral nitrate soil washing as the most telling indicator of the environmental burden, because this value illustrates the nitrate discipline with regard to the water regime. Our results are shown in Figure 4. We quantified the annual leaching of mineral nitrogen as being on the level of 4.88 kg/ha/year in treatment with a load of 0.9 LU/ha, 4.77 kg/ha/year in treatment with a load of 1.4 LU/ha, and 6.13 kg/ha/year in treatment with a load of 2.0 LU/ha. The same linear influence effect of organic input amount on nitrogen leaching was described by Behrendt *et al.* (2003).

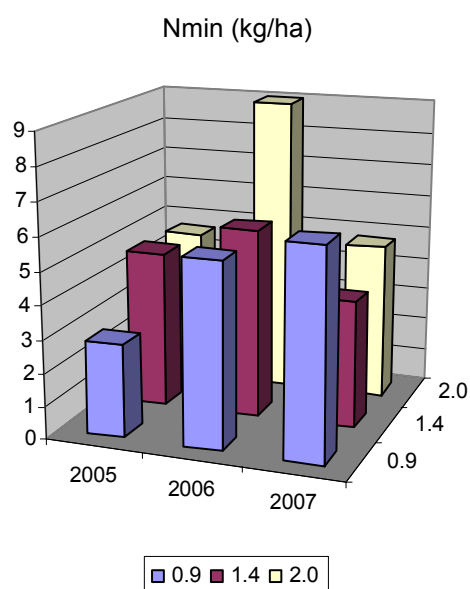


Figure 4. The leaching of mineral nitrogen by the different load (kg/ha).

Conclusion

We found no differences in nitrate and ammonia leaching between the estimated forms of organic manure; the highest leaching was with a load of 2.0 LU per hectare. From the environmental point of view grasslands are able to protect ground water against nitrate pollution with a load of 0.9 LU/ha during the year in our conditions.

Acknowledgements

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References

- Behrendt A, Schalitz G, Muller L, Schindler U (2003) The dynamics of nutrients in an extensively used pasture – pasture and lysimetric experiments. In ‘Proc. 10th Gumpensteiner lysimeter day, Gumpenstein, (A)’ pp.129-132.
- Gaisler J (2003) ‘Vliv způsobu obhospodařování travního porostu na kvalitu lyzimetrických vod. In: Ekologicky šetrné a ekonomicky přijatelné obhospodařování travních porostů’. (Book of proc.: Prague).
- Wessolek G, Reents H, Möller W, Müller P (1994) Interpretation of vertical nitrate depth profiles of sandy soils with different utilization. *Zeitschrift für Kulturtechnik und Landentwicklung* **35**, 10-20.

Effect of rice straw application on Soil Physico-chemical Properties

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Abstract

This study was conducted to investigate the effects of residual rice straw cutting height on paddy soil fertility. The average amount of rice straw residue for different cutting heights were 1,420kg/ha at 10cm, 1,850kg/ha at 15cm, 2,400kg/ha at 20cm. Among the soil physical properties, soil hardness and bulk density were decreased and porosity was increased with rice straw retention. Organic matter, available silicate content, and cation exchange capacity were dramatically decreased when rice straw was collected. The number of spikelets/m² and the percentage of ripeness was high with rice straw reduction. Rice yield was increased by 32% and 28% for cutting heights of 20cm and 15cm.

Key words

Cutting height, paddy soil, rice straw, soil fertility, physical property

Introduction

Paddy fields with low crop productivity are occupy about 67 percent of Korea (ASI 1992). The main factor for reduced productivity is the inferiority of the soil parent material. However, a main factor in the rice crop systems is that there is no chance to improve soil fertility by continuous application of organic matter of good quality (rice straw, barley straw, etc.) and soil amendments as well as leaching of microelements, such as iron and manganese and excessive application of chemical fertilizer. Rice production is influenced by soil fertility but it is difficult to maintain soil fertility by reliance on chemical fertilizer. It is desirable to improve and maintain soil fertility by application of organic matter.

Application of organic matter can ameliorate physical properties: increase porosity by aggregation of soil structure, and decrease hardness and bulk density. Also application of organic matter has improved the work efficiency of agricultural machinery with amelioration of dynamic properties such as cone penetration resistance, and the Atterberg constant (Kwun *et al.* 1984; Lee *et al.* 1986; Shin *et al.* 1975).

In recent years, maintenance of soil fertility for paddy soil involved application of rice straw, but most rice straw is collected as fodder. Collection of rice straw affected the stable production of high quality rice and a lowered paddy soil fertility. This study was carried to establish of optimum cutting height at harvest time required to maintain soil fertility on deteriorated paddy soil resulting from incineration and collection of rice straw.

Methods

This study was conducted on the Jeonbuk series soil in a paddy field at Honam Agricultural Institute from 2005 to 2008. Rice straw was harvested at several values of cutting height (10cm, 15cm, 20 cm from the ground) with a combine at rice harvest time. Conventional practices were used to collect rice straw. A machine was used to transplant medium seedlings in the last ten days of May. Amounts of applied fertilizer were decided after soil testing. Among soil physical properties measured, bulk density was determined by the core method and hardness was measured with a penetrometer (Yamanaka). Soil chemical analysis was carried out according to the analytical methods for soils and plants (NIAST 2000). Organic matter, available phosphate, and inorganic nitrogen was measured by the Tyurin, Lancaster and Kjeldahl distillation methods, respectively. Exchangeable cations were determined using a VISTA-MPX (USA) inductively coupled plasma emission spectrometer (ICP-ES) following soil extraction with 1M NH₄OAc. Investigation of the yield and growth of rice was carried out according to the standard of investigation & research on agricultural science technology (RDA 2003).

Results

The change of soil physical properties with rice straw cutting height are shown in Table 1. Physical properties were improved by rice straw retention, that is the surface soil depth was deepened, soil hardness and bulk density were decreased while porosity increased. The improvements of physical properties tended to be higher with the higher cutting heights. Application of rice straw in paddy fields of Fluvio-marine deposits have effects on deep tillage and the amelioration of drainage by reducing the imperviousness of the plow pan(Lee *et al.* 1979).

Table 1. The change of physical properties in subsoil with retention of rice straw.

Division		Surface soil depth	Hardness	Bulk density	Porosity	Three phases(%)		
Division		(cm)	(mm)	(g cm ⁻³)	(%)	Solid	Liquid	Gaseous
Control [†]		12.0	20.4	1.594	39.9	60.1	39.6	0.3
Cutting height (cm)	10	14.0	19.7	1.558	41.2	58.8	40.9	0.3
cutting height (cm)	15	14.0	19.5	1.474	44.4	55.6	43.0	1.4
cutting height (cm)	20	14.0	18.2	1.417	46.6	53.4	44.6	2.0

[†]Collection of rice straw

Table 2. The change of chemical properties in surface soil with retention of rice straw.

Division		OM (g/kg)	P ₂ O ₅ (mg/kg)	SiO ₂ (mg/kg)	CEC (cmol _c /kg)
Control [†]		Δ1.34	Δ1	Δ58	Δ0.33
Cutting height (cm)	10	Δ0.53	Δ7	Δ31	Δ0.28
	15	Δ0.49	Δ10	Δ27	Δ0.23
	20	Δ0.30	Δ27	Δ17	Δ0.22

[†]Collection of rice straw

The change of soil chemical properties with rice straw with cutting height are shown in Table 2. Cation exchangeable capacity (CEC), and content of available silicate, and organic matter decreased with rice straw retention. It is thought that application of organic matter will increase the holding capacity of nutrient due to the CEC increment. Organic matter contains trace element and nitrogen, phosphate, potassium, and the like. It has the function of nutrient supply and the buffering capacity of soil. Phosphate solubility increased according to high content of organic matter in soil (Lee *et al.* 1995).

Table 3. Rice yield and yield components

Division	Culm Length (cm)	Panicle length	No. of panicle (ea/plant)	No. of spikelets per m ² (×1,000)	Ripened grain ratio (%)	1,000 grains weight (g)	Yield of milled rice (Mg/ha)	Yield index
Control [†]	72.6	19.5	9.3	21.7	68.2	19.7	3.67	100
Cutting height (cm)	10	71.0	19.6	9.4	25.4	70.0	4.45	121
	15	72.6	18.3	9.7	26.3	76.6	4.71	128
	20	72.6	19.2	10.2	27.3	80.5	4.84	132

[†]Collection of rice straw

Rice yield and yield components are related to rice straw reduction in cutting height as shown in Table3. The number of spikelets per m² and the percentage of ripeness were high with rice straw retention. Rice yield increased when compared to conventional method (3.67Mg/ha), by 32 and 28% for cutting heights of 20 and 15cm, respectively.

Conclusion

Among the soil physical properties, soil hardness and bulk density decreased and porosity increased with rice straw restoration. While organic matter, available silicate content, and cation exchange capacity were dramatically decreased when rice straw was collected. There was a little decrease when rice straw was restored to the soil, and these effects increased with the increase restored amount of rice straw as affected by cutting height. The number of spikelets/m² and the percentage of ripeness was high with rice straw reduction.

References

- ASI (1992) General remarks of Korean soils. Agricultural Sciences Institute. Suwon. Korea. p.308-610.
- Kwun KC, Kim JK, Kim IY, Park SH, Jo DS (1984) Effects of continuous fertilizations on physical and chemical properties of paddy soil and growth of rice plant. *Res.Rept. ORD 26 (crop)*, 67-76.
- Lee SY, Choi DH, Kwon TO, So JD, Park NP, Ham YS (1979) The effects of the mole drainage and deep plowing with heavy fertilizer, soil amendment application on rice in the degraded Fluvio-Marine Deposit soils. *Res. Rept. ORD 21*, 39-55.
- Lee CH, Lee HS, Choi SL, Shin WK, Lee RS (1986) Effects of organic matters application with the different levels of nitrogen fertilizer over a 5 year on the soil physico-chemical properties and rice yields. *Korean Journal of Soil Science and Fertilizer 19*, 25-31.
- Lee KB, Kang JG, Uhm TY, Kim JG, Kim SK, Lee GS (1995) The effect of long-term organic matter application on N, P and K uptake by rice in paddy soil. *RDA. J. Agri. Sci.* **37**, 291-297.
- NIAST (2000). Methods of soil and crop plant analysis. National Institute of Agricultural Science and Technology. Suwon. Korea.
- RDA (2003) Investigation and standard for agricultural experiment. Rural Development Administration. Suwon. Korea.
- Shin JS, Shin YH (1975) The effect of long-term organic matter addition on the physico-chemical properties of paddy soil. *Korean Journal of Soil Science and Fertilizer 8*, 19-23.

Effectiveness of water and nutrient BMPs to meet regulatory requirements for commercial strawberry production in Florida, USA

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Abstract

Current US federal regulations require individual states to identify impaired water bodies and establish total maximum daily loads (TMDLs) for pollutants entering these water bodies. TMDLs establish the maximum amount of pollutants that can be discharged to a water body and still meet designated uses such as swimming, fishing, or as a potable water use. Florida regulations require identification, verification and adoption by law the best management practices (BMPs) for agricultural non-point sources for large number of crops grown in Florida. The objective of this project was to evaluate the effectiveness of currently-used water and nutrient BMPs for winter strawberry production in Florida to achieve TMDL regulatory limits. The ultimate goal of the project was to provide evidence as to which current BMPs are effective and encourage farmers to adopt water and nutrient management practices that reduce contamination to shallow groundwater, surface runoff and surface water bodies. Results from 4 years of monitoring showed that consistently, for the most part, current BMPs used are very effective in managing nutrient losses. This study was used to establish criteria for accepted BMPs that would qualify strawberry growers for presumed compliance status, exempting them from regulatory penalties for exceeding TMDL limits.

Key Words

Drip irrigation, nutrient loss, groundwater contamination.

Introduction

Florida's Nonpoint Source Management Program was established in 1978 and has undergone numerous changes over the years. The program requires the use of structural and nonstructural BMPs to minimize nonpoint source pollution, either through traditional regulation (i.e., Environmental Resource Permits) or through voluntary measures (i.e., implementation of BMPs). Section 303(d) of the FCWA also requires states to identify impaired water bodies and establish total maximum daily loads (TMDLs) for pollutants entering these water bodies. TMDLs establish the maximum amount of pollutants that can be discharged to a water body and still have it meet designated uses such as swimming, fishing, or as a potable water use. Once a TMDL is set, an implementation plan must be developed that specifies the activities that watershed landowners will undertake to reduce point and nonpoint source pollutant loadings. Many of the 44,000 commercial farmers who produce food, fiber, and livestock on approximately 10 million acres in Florida will be required to meet specific water quality load allocations. Water quality targets will be achieved through a combination of regulatory, non-regulatory, and incentive-based measures.

To address TMDLs, the Florida legislature passed the 1999 Florida Watershed Restoration Act that gives the Florida Department of Agriculture and Consumer Services (FDACS) the authority to develop interim measures, BMPs, cost-share incentives, and other technical assistance programs to assist agriculture in reducing pollutant loads in target watersheds. This law defines a process for the development of TMDLs for impaired waters as required by section 303(d) of the Federal Clean Water Act. It directs the FDACS to identify and adopt by rule BMPs for agricultural nonpoint sources. The Florida Department of Environmental Protection (FDEP) must also verify that these BMPs are effective at reducing pollutant loading to these waters. By law, agricultural producers who voluntarily implement these BMPs, which have been verified effective and adopted by rule, will receive a presumption of compliance with state water quality standards. They will also be eligible for cost-share money to implement selected BMPs once eligible practices are identified. The objectives of this study were: 1) To assess, for the various crop production scenarios, nutrient load potential of nitrogen from subsurface leaching and surface runoff; 2) to assist growers in adopting water and fertilizer management technologies that will reduce the amount of fertilizer nutrients (with emphasis on nitrogen) leaching each year from typical crop production systems; and 3) to assist growers in utilizing state-of-the-art, often computer-based, on-farm decision-making packages to best manage their fertilizer inputs for minimization of groundwater and surface water contamination.

Methods

This 4-year project was conducted on 11 commercial grower/cooperator operation sites. These locations represented 14 different soil types. Leachate samples were collected weekly to determine the volume and $\text{NO}_3\text{-N}$ -concentration in leachate that had moved beyond the root zone. A passive wick-type leachate collector using fiberglass rope was constructed of PVC and installed in a plant bed, directly below a drip irrigation emitter, below the rooting zone (~ 45 cm below the top of the bed). There were 21 sampling sites consisting of 8 leachate samplers (replicates) per site. Samples were analyzed using an Alpkem Rapid Flow Analyzer (Model RFA/2). Weekly samples were used to determine cumulative $\text{NO}_3\text{-N}$ losses for each site and were compared to soil type and grower practices to determine if any relationships were evident. Samples were collected from Nov to May (2004-2008).

Strawberry production in central Florida used methyl bromide fumigated raised-bed culture with black plastic mulch (Olsen and Simonne 2008). Bare-root transplants were set during the month of October (35,000 plants /ha, double rows 60 cm apart, 38 cm in row spacing) and established with overhead irrigation. All water and nutrient management decisions were made by the grower/cooperator. Harvests were made as needed until grower determined that market conditions warranted ending the production season (late March or early April). Cultural information was solicited from each grower to determine irrigation and fertilizer application scheduling, microirrigation tube type, emitter spacing and application rates, seasonal liquid and dry fertilization rates, and other information.

Results

Individual grower cultural information was evaluated and resulted in the following: 1) all growers used drip irrigation to provide water and nutrients for crop growth; 2) drip tube emission rates were from 3 to 6 l/min per 100 m of bed; 3) daily irrigation application rates ranged from 0.3 to 0.6 cm/day depending stage of season; 4) approximately 50% of the growers used a preplant dry fertilizer application (31 kg N /ha average) and 50% used no preplant fertilizer; 5) average liquid fertilizer application amounts ranged from 0.56 kg to 4 kg N /ha/day depending on crop stage (seasonal average of 1.2 kg N /ha/day). This information revealed that participants in the study were applying on average 180 kg N /ha for the season. The recommended seasonal rate was 150 kg /ha (Olsen and Simonne 2008). The majority of sites showed seasonal cumulative nitrate-N leaching was < 5kg /ha (Figure 1). Overall, there was little seasonal variability of nitrate-N leached from each site at each farm. Individual farm irrigation and nutrient management likely influenced the overall leached N when compared to other farms. Figure 2 shows the average seasonal cumulative leaching for each year, with all sites on all farms combined. Differences among seasons were always less than 0.5 lbs of N at any time, indicating the repeatability of the results from year to year.

Considerable variability that can be experienced when conducting such a study on commercial production fields is common, but the results from this study were remarkably consistent from year to year. However, when one considers the BMPs that strawberry producers are currently implementing, the results should not be surprising. All of the growers in this study (and up to 95% of the industry) use drip irrigation as the means of providing water and nutrients to the crop. Strawberries are very prone to salt damage, therefore producers accepted microirrigation many years ago primarily because of its ability to provide liquid fertilizer when and where is it needed. The water conservation advantages of microirrigation were secondary. Since accumulated fertilizer salts should to be avoided, producers are careful not to over-apply N, and since irrigation management goes hand-in-hand with nutrient management, care was taken to not to leach the applied nutrients below the root zone.

In conclusion, for the cooperators that were participating in this study, current strawberry production practices appear to be adequate for managing nitrate-N losses from production fields. We assume that this will be true for other growers using similar management practices. This study was also important for increasing grower participation in Florida's voluntary BMP participation program.

References

Olson SM, Simonne E (2005) 'Vegetable Production Handbook for Florida'. (Vance Pub.: Lenexa, KS).

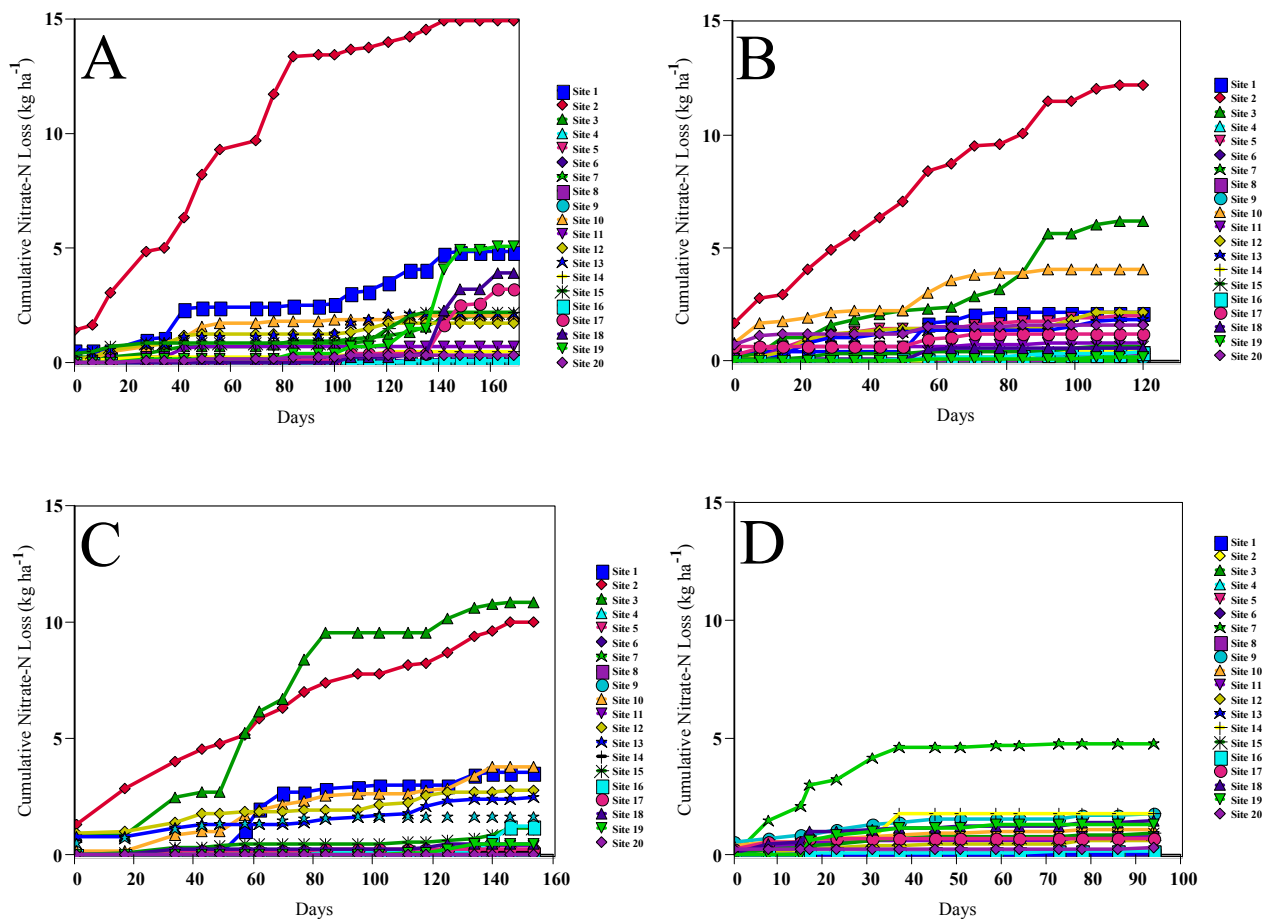


Figure 1. Mean cumulative nitrate-N leaching losses for each sampling site for A) 2004-05; B) 2005-06; C) 2006-07; and D) 2007-08 production seasons.

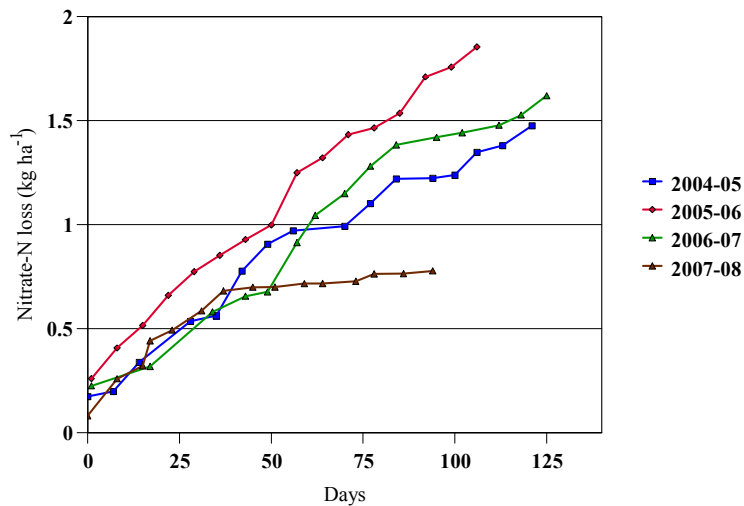


Figure 2. Mean cumulative nitrate-N leaching losses for all sites combined for each production season.

Effects of brewery wastewater irrigation on Antofagasta soils

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Abstract

Saline soils, common to the Antofagasta region of Chile, limit agricultural activity, the use of phytoremediation and the development of energetic crops. The aim of this work was to evaluate the effects of leaching with brewery wastewater and distilled water on the soil profile by using column assays in order to improve the conditions of saline soils by removing salts. Conductivity and pH were measured in leachate samples and in the soil profile. The results showed that the application of distilled water and brewery wastewater had similar effects, although different in their magnitude, on the conductivity and pH in the soil leachates, but caused different behavior in these variables in the soil profile. The pH values in leachate samples increased from 7.5 to 8.5 and from 8.3 to 9.2 when distilled water and brewery wastewater were used. Conductivity decreased from 18 to 3 mS/cm and from 18 and 7 mS/cm when distilled water and brewery wastewater were used. Distilled water maintained the pH around 8.3 in the soil profile meanwhile the use of brewery wastewater kept the pH around 7.3. Both irrigation solutions decreasing the conductivity in the soil profile reached values between 0.8 and 2.1 mS/cm. It was possible to decrease the conductivity of the soil profile by using distilled water and brewery wastewater as an irrigation solution, although brewery wastewater had high initial conductivity (4.7 mS/cm). In addition, brewery wastewater enabled the pH to be kept constant (around 7.3) in the soil profile. The result indicated that brewery wastewater may be used in the first stage to improve the quality of the saline soil of the Antofagasta Region.

Key words

Irrigation, saline soil, conductivity, brewery wastewater, pH.

Introduction

In the arid zones of northern Chile, the salinity of soils and the availability of water resources are common problems that limit agricultural activities. In addition to salinity, another problem associated with these soils is the lack of organic matter. The climate of the study area is extremely arid with an annual average rainfall of approximately 4 mm and a high UV index. The main daily temperature is 13°C in winter and 20°C in summer (Vargas 2000). Excessive amounts of salts have adverse effects on the physical and chemical properties of soil, microbiological processes and on plant growth (Tejada *et al.* 2006). The soils of the Atacama Desert (Electrical Conductivity (EC) > 10 mS/cm) are characterized as saline soils (Godoy-Faúndez *et al.* 2008). In Chile, studies on arid soils have mainly focused on the remediation of soils contaminated with heavy metals or fuel by mining operations; few studies have been performed on saline soils for agricultural purposes.

Irrigation with fresh freshwater would be an ideal option for improving saline soil quality, but since freshwater resources are scarce, wastewater represents an alternative water source. Some wastewaters are a potential fertilizer when used to irrigate arid zones. They contain organic matter and macronutrients, which is highly beneficial. The aim of this work was to evaluate the effects of leaching with brewery wastewater and distilled water on soil profile using columns assays, to improve the conditions of saline soils by removing salts.

Methods

Soil Samples

Surface soil samples (0-30 cm) were obtained from the commune of Antofagasta. The soil was dried at 65°C for 48 hours and passed through a 2 mm mesh. The pH and EC were determined using saturation extract. Soil pH and EC were measured using a Bench pH/Conductivity Meter Oakton. Organic matter and water content were determined according Sadzawka *et al.* (2006).

Brewery wastewater

Brewery wastewater was obtained from the brewery industry. The properties of the wastewater, such as pH, EC, chemical oxygen demand (COD), color, volatile solids (VS) and total solids (TS) were determined. EC and pH were measured using a Bench pH/Conductivity Meter Oakton. Color was measured at a 455 nm wavelength (Hach Spectrophotometer). COD, VS and TS were determined according to APHA (2002).

Leaching assay

To perform the soil column leaching experiment, plastic columns (25.2 cm length and 5.2 cm internal diameter) were used, filled with approximately 0.4 kg soil and 0.4 kg gravel (ratio 1:1), achieving a bulk density of $1.628 \times 10^{-3} \text{ kg/cm}^3$. The columns were connected at the output to a peristaltic pump (Masterflex) with an outflow rate of $1.4 \text{ cm}^3/\text{min}$. The leaching column experiments were done in three replicates at a room temperature of 19-20 °C (Navia *et al.* 2005).

The soil columns were leached with distilled water and with wastewater and the columns were saturated at the beginning of the irrigation assays, and a 5 cm irrigation solution level was maintained on the top of each soil column. Leachate samples of 100 mL were collected for EC and pH analysis. After leaching was completed, the soil columns were allowed to drain free, and then cut into 5 sections of 3.5 cm each, from the top of the column downwards. Soils samples were dried at 65°C for 48 hours and were analyzed for pH, EC.

Statistical analysis

All data reported are the means of three determinations. Conductivity and pH in the different soil profile were analyzed by analysis of variance. Significant differences were determined at $P \leq 0.05$.

Results and Discussion

Table 1 shows the physicochemical characterization of the Antofagasta soil. The organic matter content was low (< 0.5%), associated with the extreme aridity of the zone due the lack of precipitation and the high level of evaporation. The characterization of brewery wastewater is given in Table 2. Brewery wastewater has a high COD value directly related to the color associated with the organic compounds generated by this kind of industry. The pH was highly alkaline.

Table 1. Characterization of the Antofagasta soil

Parameter	Conductivity (mS/cm)	pH	Water content (%)	Organic matter (%)
	5.03±0.4	7.13±0.1	0.21±0.02	< 0.5

Table 2. Characterization of the brewery wastewater

Parameter	Conductivity (mS/cm)	pH	Total solid (g/L)	Volatile solid (g/L)	COD (mg/L)	Color (UPt-Co)
	4.7±0.3	10 ±0.01	10.07±0.3	7.7±0.9	10.800	1068±6

The variation of pH in the leachate samples using distilled water and brewery wastewater are shown in Figure 1. When both solutions were used, an increase in pH values from 7.5 to 8.5 was observed in the leaching samples with distilled water, and from 8.3 to 9.2 with brewery wastewater.

The variation of pH in the soil profile using both irrigation solutions is shown in Figure 2. It was observed that the pH value in the soil profile with the distilled water irrigation decreased in depth (from 8.4 to 8.1), whereas using brewery wastewater the pH was constant around 7.3.

For the use of distilled water, an increase in the pH of the leaching samples was noted, as was a decrease in the pH values in the soil profile. This may be attributable to the release of OH⁻ ions from the soil. In the case of brewery wastewater, the pH value in leaching samples increased, whereas the pH value in the soil profile was constant, with a tendency to increase. The organic matter present in brewery wastewater acts as a buffer, keeping the pH value constant (Tan 1993).

The variations in the conductivity of the soil leaching samples are shown in Figure 3. A decrease in the conductivity values was observed with an increase in the volume of the irrigation solution. The conductivity values present in the leachates of brewery wastewater were higher (ranging between 18 and 8 mS/cm) than leachates from distilled water (ranging between 18 and 4 mS/cm). This can be explained by the initial conductivity of brewery wastewater.

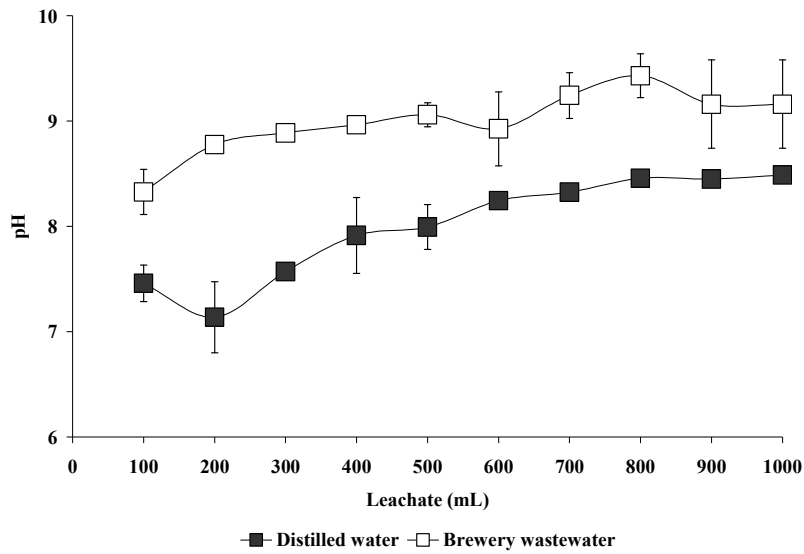


Figure 1. Variation of pH in the soil leachates.

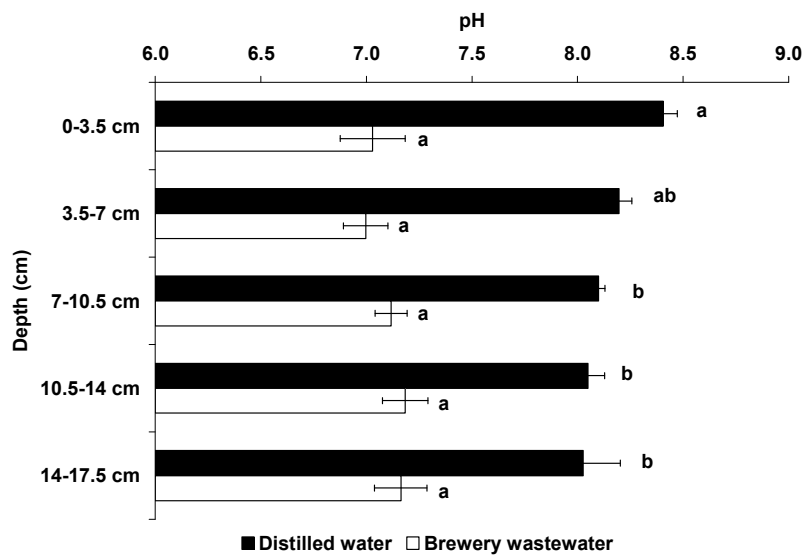


Figure 2. Variation of pH in the soil profile

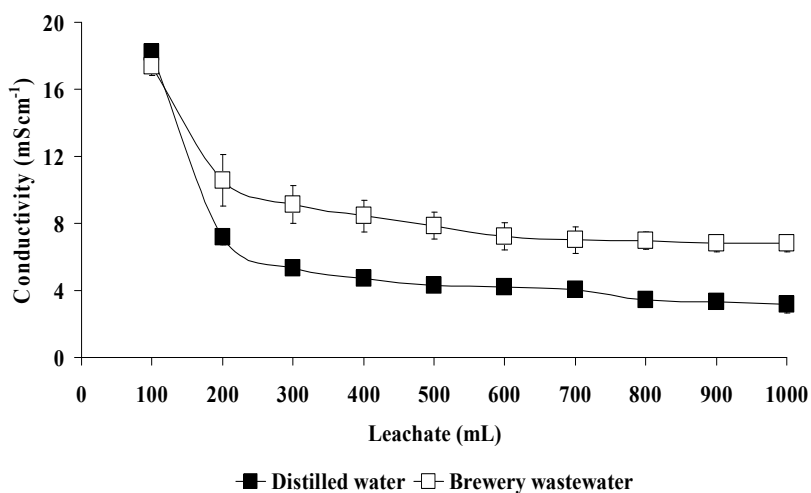


Figure 3. Variation of the conductivity in soil leachates.

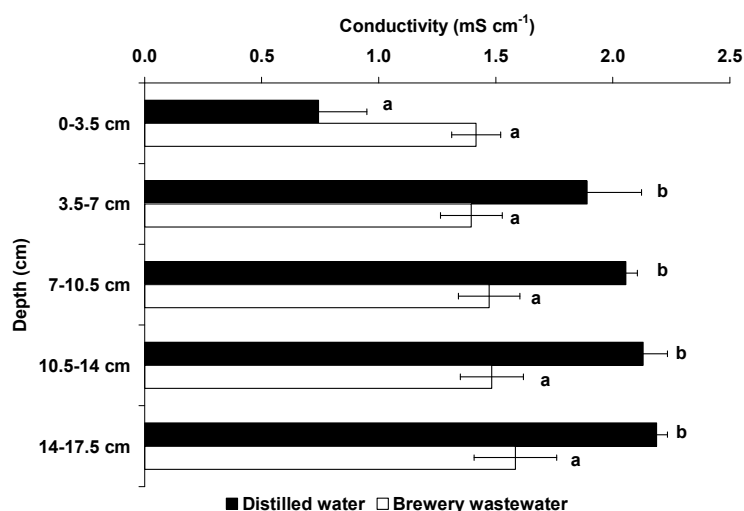


Figure 4. Variation of the conductivity in the soil profile.

The variation of conductivity in the soil profile is shown in the Figure 4. The irrigation with distilled water caused a decrease in conductivity at the 0-3.5 cm depth and an increase at the next depth. This behavior may be related to a displacement of salts from the first profile (0-3.5 cm) to the second profile (3.5-7 cm). In the case of brewery wastewater, salt mobilization was not observed; this is likely due to the addition of salt from the brewery wastewater. However, brewery wastewater irrigation causes a decrease in the conductivity of the soil. The application of distilled water and brewery wastewater has a similar effect on the conductivity and pH in the soil leachates but generates a different behavior in these variables in the soil profile. More studies about irrigation and the incorporation of organic matter are required in order to develop an appropriate procedure that allows the amelioration of soils in arid zones.

Conclusions

The irrigation with brewery wastewater improved the physicochemical characteristics of the Antofagasta soil. This is reflected by a decrease in the salt concentration due to leaching of the excess salts and by the stabilization of the soil pH produced by the incorporation of organic matter. Brewery wastewater may be used in the first step to improve the quality of saline soil where natural water is scarce, as is the case in the Antofagasta Region.

Acknowledgements: DGIP Project, UCN, 2009. Development of an organo-mineral adsorbent for the adsorption of heavy metals from wastewater.

References

- APHA (1992) Standard Methods for the Examination of Water and Wastewater, APHA/WWA-WPCF, Washington D.C.
- Godoy-Faúndez A, Antizar-Ladislao B, Reyes-Bozo L, Camaño A, Sáez-Navarrete C (2008) Bioremediation of contaminated mixtures of desert mining soil and sawdust with fuel oil by aerated in-vessel composting in the Atacama Region (Chile). *Journal of Hazardous Materials* **151**, 649-657.
- Navia R, Fuentes B, Lorber KE, Mora ML, Diez MC (2005) In-series columns adsorption performance of Kraft mill wastewater pollutants onto volcanic soil. *Chemosphere* **60**, 870-878.
- Sadzawka A, Grez R, Mora ML, Saavedra NR, Carrasco MA y Rojas CW (2004) 'Métodos de análisis recomendados para los suelos de Chile. Revisión 2006. Instituto de Investigaciones Agropecuarias, Serie Actas INIA N°34, Santiago, Chile.
- Tan KH (1993) 'Principles of soil chemistry' (Marcel Dekker INC: USA)
- Tejada M, García C, González J, Hernández M (2006) Use of organic amendment as a strategy for saline soil remediation: influence of the physical, chemical and biological properties of soil. *Soil Biology & Biochemistry* **38**, 1413-1421.
- Vargas G, Ortlieb L, Rutllant J (2000) Aluviones históricos en Antofagasta y su relación con eventos el Niño/Oscilación del Sur. *Revista Geológica Chile* **27**.n 2.

Efficiency of water use for sorghum, beans, and sesame affected by ground water table

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Abstract

Pot experiments using lysimeters with 5 depths of ground water table (GWT); 0, 25, 50, 75, and 100cm, respectively were conducted to investigate crop biomass, water use efficiency, and changes of soil moisture for sorghum, beans and sesame. All the lysimeters were randomized with four replication arrangements were filled up with soils and were adjusted to constant bulk density, treated twice water infiltration from bottom to top of lysimeter. Dry weight of above ground part of sesame was gradually increased with deeper GWT showing the highest in the plot of 100cm GWT. Beans had the highest tolerance against excess moisture condition while sesame showed the lowest tolerance being a serious obstacle to crop growth. Water use efficiency of the experimental crops in condition of saturated soil was significantly decreased compared with normal moisture condition of soils. Consequently estimation of GWT for maximum amount of evapotranspiration was 35.6cm, 16.5cm, and 9.6cm for sorghum, sesame, and beans, respectively.

Key Words

Lysimeter, evapotranspiration, sorghum, beans, sesame, ground water table, water use efficiency.

Introduction

Evapotranspiration information is required for many applications in agricultural and natural resource management from hydrological applications to plant growth and yield models to irrigation scheduling recommendation. Early observations of diurnal shallow water table fluctuation were made by White (1932), Troxell (1936), and Meyboom (1967). White (1932) proposed a method that utilizes observation of shallow water table fluctuation to estimate the direct consumption of groundwater by plants. Even lysimeters that are used for measuring water use by irrigated crops were found to give inaccurate estimates of evapotranspiration when the state. The object of this paper is to evaluate crop biomass and water use efficiency such as evaporation and evapotranspiration affected by shallow ground water table conditions ranging from 0 cm to 100 cm.

Material and methods

Lysimeter controlled with 5 depths of ground water table; 0, 25, 50, 75, and 100 cm, respectively was made by PVC pipe with 30 cm diameter to investigate crop biomass, water use efficiency, and changes of soil moisture for Sorghum, Beans, and Sesame cultivation. All the lysimeters were randomized with four replications were filled with soils and adjusted to constant bulk density by water infiltration from bottom to top of the lysimeter. The seedlings (17 days after seeding) of Sorghum, Beans, and Sesame were transplanted on May 7, 2007 and harvested on July 12, 2007 for Sorghum and on July 23, 2007 for Beans and Sesame. Evaporation from lysimeter grown without crop and evapotranspiration from lysimeter grown with crop were measured everyday by amount of water consumption in water supplying bottle. Therefore transpiration was calculated by difference between evapotranspiration and evaporation measurement. Also bulk moisture content of soils during the growing season was measured by TDR sensor installed at different soil depth from surface with 25cm interval. Air temperature and humidity during the growing season were measured by data logger with a 30 minute interval.

Results

Dry weight of above ground part of sesame gradually increased with deeper GWT being the highest in the plot of 100cm GWT. Dry weight of sorghum was the highest in the plot of 50cm GWT showing the following order of 75cm>100cm>25cm GWT while that of beans was the highest in the plot of 25cm GWT showing the following order of 0cm>50cm>75cm>100cm GWT. Beans have the highest tolerance against excess moisture condition while sesame showed the lowest tolerance showing a serious obstacle in crop growth (Table 1).

Table 1. Above-ground dry matter of crops affected by different ground water table.

Crop	Growth period	GWT-0cm		GWT-25cm		GWT-50cm		GWT-75cm		GWT-100cm	
		DW	Index	DW	Index	DW	Index	DW	Index	DW	Index
Sorghum	66days	93.1	56.7	161.4	98.1	220.1	130.8	180.9	113.9	175.1	100.0
Sesame	77days	81.7	55.7	114.7	74.9	112.1	61.6	124.9	72.8	179.8	100.0
Beans	77days	189.8	141.2	248.7	174.5	186.6	124.2	150.3	94.7	151.7	100.0

Evapotranspiration ratio calculated by total amount of evapotranspiration (g) per dry weight of above ground part (g) in the plot of 100cm GWT were 82, 195, 178 for sorghum, sesame, and beans, respectively compared with 275, 420, 293 in the plot of 0cm GWT, respectively. Consequently water use efficiency of the experimental crops in condition of saturated soil was significantly decreased compared with normal moisture condition of soils (Table 3). Consequently estimation of GWT for maximum amount of evapotranspiration were 35.6 cm, 16.5 cm, and 9.6 cm for sorghum, sesame, and beans, respectively (Table 4)

Table 2. Total amount of evapotranspiration affected by different GWT during the growing season.

Crop	GWT-0cm (L/lysimeter ⁻¹)	GWT-25cm (L/lysimeter)	GWT-50cm (L/lysimeter)	GWT-75cm (L/lysimeter)	GWT-100cm (L/lysimeter)
Sorghum	24.83	29.74	30.27	22.89	14.45
Sesame	27.49	40.37	21.77	15.06	15.56
Beans	54.75	63.64	52.28	32.75	27.00

Table 3. Evapotranspiration ratio affected by different GWT during the growing season.

Crop	GWT-0cm	GWT-25cm	GWT-50cm	GWT-75cm	GWT-100cm
Sorghum	275	168	138	130	82
Sesame	420	396	260	196	195
Beans	293	261	280	209	178

*Evapotranspiration ratio was calculated by above-ground dry matter (g) / total amount of evapotranspiration (g)

Table 4. Optimum ground water table for maximum evapotranspiration of crop.

Crop	Regression equation (0cm < X < 100cm)	Ground water table at maximum evapotranspiration
Sorghum	Y=-0.004x ² +0.285x+25.015	35.6
Sesame	Y=-0.0015x ² -0.0494x+32.043	16.5
Beans	Y=-0.0043x ² +0.0825x+58.01	9.6

Conclusion

Dry weight of above ground part of sesame was gradually increased with deeper GWT showing the highest in the plot of 100cm GWT. As the results, beans have the highest tolerance against excess moisture condition while sesame showed the lowest tolerance showing a serious obstacle in crop growth. And water use efficiency of the experimental crops in condition of saturated soil was significantly decreased compared with normal moisture condition of soils.

References

- Meyboom P (1967) Groundwater studies in the Assiniboine River drainage basin: II Hydrologic characteristics of phreatophytic vegetation in south-central Saskatchewan. *Geol. Survey of Canada Bull.* **139**, (GSC: Ottawa).
- Troxell HC (1936) The diurnal fluctuation in the groundwater and flow of the Santa Ana River and its meaning. *Trans. Am. Geophys. Union* **17**, 496-504.
- White WN (1932) A method of estimating groundwater supplies based on discharge by plants and evaporation from soil: Results of investigation in Escalante Valley, Utah. *Water Supply Paper* **695**, -A. (USGS: Reston, VA).

Evaluation of Crop Biomass and Water Use Efficiency for Feed barnyard grass, Feed corn, and Coix Affected by Ground Water Table

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Abstract

Pot experiment using lysimeter controlled with 5 depths of ground water table (GWT); 0, 25, 50, 75, and 100cm, respectively were conducted to investigate crop biomass, water use efficiency, and changes of soil moisture for feed barnyard grass, feed corn, and Coix. All the lysimeter randomized with four replication arrangements were filled up soils and were adjusted to the constant bulk density treated with twice water infiltration from bottom side to upper side of lysimeter. Dry weights of above ground part of feed barnyard grass and feed corn grown on the plot of 75cm GWT were the highest showing the following order of 50cm > 100cm < 0 & 25cm GWT while that of coix was gradually increased with increase of GWT showing the highest in the plot of 100cm GWT. Total amount of evapotranspiration affected by different ground water tables during the growing season of crop showed the same tendency as that of dry weight. Evapotranspiration ratio calculated by evapotranspiration volume(ml) per dry weight(g) were 110.6~163.6ml for feed barnyard grass, 101.4~143.6ml for feed corn, and 133.0~210.0ml for coix showing the order of coix>feed barnyard grass>feed corn. Evapotranspiration ratio was increased with decrease of GWT that is the saturation condition of soil moisture. Estimation of GWT for maximum amount of dry weight of upper part of feed barnyard grass was 97cm. However those of feed corn and coix were increased with increase of GWT showing the almost linear equation.

Key Words

Lysimeter, Evapotranspiration, Feed barnyard grass, Feed corn, Coix, Ground water table, Water use efficiency

Introduction

Evapotranspiration information is required for many applications in agricultural and natural resource management from hydrological applications to plant growth and yield models to irrigation scheduling recommendation. Early observations of diurnal shallow water table fluctuation were made by White (1932), Troxell (1936), and Meyboom (1967). White (1932) proposed a method that utilizes observation of shallow water table fluctuation to estimate the direct consumption of groundwater by plants. Even lysimeters that are used for measuring water use by irrigated crops were found to give inaccurate estimates of evapotranspiration when the state The objective of this paper is to evaluate crop biomass and water use efficiency such as evaporation and evapotranspiration affected by shallow ground water table conditions ranging from 0cm to 100cm.

Methods

Lysimeter controlled with 5 depths of ground water table; 0, 25, 50, 75, and 100cm, respectively was made by PVC pipe with 30cm diameter to investigate crop biomass, water use efficiency, and changes of soil moisture for Whole-crop barley, Rye, Pearl millet, All the lysimeter randomized with four replication arrangements were filled up soils and were adjusted to the constant bulk density by twice water infiltration from bottom side to upper side of lysimeter. The seedlings of Feed barnyard grass were on April 7, 2008, and Feed corn were on April 21, 2008 and Coix were on April 28, 2008 and harvested on June 2, 2008 for Feed barnyard grass, June 28, 2008 for feed corn, and July 9, 2008 for Coix. Evaporation from lysimeter grown without crop and evapotranspiration from lysimeter grown with crop were measured everyday by amount of water consumption in water supplying bottle. So transpiration was calculated by difference between evapotranspiration and evaporation measurement. Also bulk moisture content of soils during the growing season was measured by TDR sensor installed at different soil depth from surface with 25cm interval. Air temperature and humidity during the growing season were measured by data logger with 30 minute interval.

Results

Table 1. Above-ground dry matter of crops affected by different ground water table

Crop	Growth period	GWT-0cm		GWT-25cm		GWT-50cm		GWT-75cm		GWT-100cm	
		DW	Index	DW	Index	DW	Index	DW	Index	DW	Index
Feed barnyard grass	56days	94.7	79.5	59.9	50.4	133.6	112.3	152.9	128.4	119.0	100.0
Feed corn	68days	199.7	69.7	193.4	67.5	244.1	85.2	310.4	108.3	286.6	100.0
Coix	72days	91.3	62.5	109.9	75.2	127.9	87.5	127.8	87.4	146.2	100.0

Dry weights of above ground part of feed barnyard grass and feed corn grown on the plot of 75cm GWT were the highest showing the following order of 50cm > 100cm < 0 & 25cm GWT while that of coix was gradually increased with increase of GWT showing the highest in the plot of 100cm GWT. As the results, all the crop have a little tolerance against excess moisture condition of 0cm and 25cm GWT showing a remarkable decrease of dry weight of crop (Table 1).

Table 2. Total amount of evapotranspiration affected by different GWT during the growing season

Crop	GWT-0cm	GWT-25cm	GWT-50cm	GWT-75cm	GWT-100cm
Feed barnyard grass	15.48	14.11	15.75	16.05	13.16
Feed corn	28.68	28.21	29.10	33.24	29.06
Coix	19.18	19.42	19.75	18.72	19.45

GWT ; ground water table

Total amount of evapotranspiration affected by different ground water tables during the growing season of crop showed the same tendency as that of dry weight showing the highest in plot of 75cm GWT for feed barnyard grass and feed corn while in the 100cm GWT for coix (Table 2).

Table 3. Evapotranspiration ratio affected by different GWT during the growing season

Crop	GWT-0cm	GWT-25cm	GWT-50cm	GWT-75cm	GWT-100cm
Feed barnyard grass	163.55	235.43	117.87	104.98	110.59
Feed corn	143.61	145.89	119.21	107.08	101.41
Coix	209.99	176.65	154.36	146.44	133.00

*GWT ; ground water table

**Evapotranspiration ratio was calculated by total amount of evapotranspiration(g) / above-ground dry matter(g)

Evapotranspiration ratio calculated by evapotranspiration volume(ml) per dry weight(g) were 110.6~163.6ml for feed barnyard grass, 101.4~143.6ml for feed corn, and 133.0~210.0ml for coix showing the order of coix>feed barnyard grass>feed corn. Evapotranspiration ratio was increased with decrease of GWT that is the saturation condition of soil moisture (Table 3).

Table 4. Ground water table at the highest dry weight estimated by regression equation

Crop	Regression equation(0<x<100)	Ground water table (cm)
Feed barnyard grass	$Y=-0.006x^2+1.1687x+76.168$	97
Feed corn	$Y=-0.0022x^2+1.384x+185.91$	Linear increase
Coix	$Y=-0.0021x^2+0.7223x+92.475$	Linear increase

Estimation of GWT for maximum amount of dry weight of upper part of feed barnyard grass was 97cm. However those of feed corn and coix were increased with increase of GWT showing the almost linear equation.

Conclusion

Dry weights of above ground part of feed barnyard grass and feed corn grown on the plot of 75cm GWT were the highest showing the following order of 50cm > 100cm < 0 & 25cm GWT while that of coix was gradually increased with increase of GWT showing the highest in the plot of 100cm GWT. Evapotranspiration ratio calculated by evapotranspiration volume(ml) per dry weight(g) were 110.6~163.6ml for feed barnyard grass, 101.4~143.6ml for feed corn, and 133.0~210.0ml for coix showing the order of coix>feed barnyard grass>feed corn. Estimation of GWT for maximum amount of dry weight of

upper part of feed barnyard grass was 97cm. However those of feed corn and coix were increased with increase of GWT showing the almost linear equation.

References

- Meyboom P (1967) Groundwater studies in the Assiniboine River drainage basin: II Hydrologic characteristics of phreatophytic vegetation in south-central Saskatchewan. Geol. Survey of Canada Bull. 139(64). GSC, Ottawa.
- Troxell HC (1936) The diurnal fluctuation in the groundwater and flow of the Santa Ana River and its meaning. *Trans. Am. Geophys. Union* **17**, 496-504.
- White WN (1932) A method of estimating groundwater supplies based on discharge by plants and evaporation from soil: Results of investigation in Escalante Valley, Utah> Water Supply Paper 695-A. USGS, Reston, VA. 706

Forest hydrology research with lysimeter in the northeast German lowlands special methods and results for the forest management

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Abstract

Broad areas of the northeast German lowlands are characterised by low precipitation, distinct periods of summer drought and sandy soils. In this region, forest hydrology research looks into the influence of differently structured forest on the landscape hydrology. The aim is to provide scientific guidance in the development of productive forests that enhance the quantity and quality of seepage water. In unconsolidated rock substrate lysimeters can be used to measure seepage and evaporation. The use of different types of lysimeters in the Eberswalde region has a tradition of more than 100 years. In 1972, nine new large-scale lysimeters with a depth of 5 m and a surface area of 100 m² were installed and were planted with different tree species. To investigate the impact of intensified drought on forest regeneration and tree growth special small-scale lysimeters and a field laboratory (Drylab) were constructed and used. The paper informs about the groundwater recharge under different tree species and about investigations of the water consumption of small forest trees in the face of increasingly limiting water resources arising from climate change.

Key Words

Forest lysimeter, vegetation structures, water budget, water stress.

Introduction

Given its current low precipitation levels and predominantly sandy soils with low water retention capacity, the lowlands in northeastern Germany are regarded one of the country's regions with the highest vulnerability to a climate change bringing more frequent and more intense drought periods in the future (Schröter *et al.* 2005). In northeastern Brandenburg, the long-term annual precipitation of about 570 mm is well below the overall national average of 780 mm (Müller 2002). With a forested area of 1.1 million ha, covering 35.3% of its surface area, Brandenburg, including Berlin, is the state with the fourth largest forest area in Germany (BMVEL 2008). The forest has a major effect on the landscape hydrology as a consequence of its multi-layered structure and its expanse. Therefore investigations into relationships among site, forest structure and water regime in the region are of particular interest. In view of the anticipated intensification of drought in wide areas of northern and central Germany as a consequence of climate change, the forest hydrology studies presented here may provide some direction for many other regions in Germany, particularly investigations of water consumption and forest growth in the case of declining water resources during the growing season.

Table 1. Types of lysimeters used in forest hydrology research at Eberswalde.

Year	1907	1929	1966	1972	1994	2005	2009
Site	Eberswalde "Drachenkopf"	Eberswalde "Drachenkopf"	Liepe	Britz	study sites	Britz "Postluch"	Eberswalde open field laboratory "Drylab"
Lysimeter type	smallest scale lysimeter	small-scale lysimeter	sub-surface lysimeter	large-scale lysimeter	small-scale lysimeter	groundwater lysimeter	small-scale lysimeter
Weighability	non-weighable	weighable	non- weighable	non- weighable	weighable	weighable	non- weighable
Soil	disturbed	disturbed	undisturbed	disturbed	undisturbed	undisturbed	disturbed
Surface area	500 cm ²	1 m ²	500 cm ² , 1500 cm ²	100 m ²	1 m ²	1 m ²	2 m ²
Depth	1.0 m	1.5 m	5 m	5 m	1.8 m	2.0 m	1.5 m

Methods

Lysimeters are appropriate for ascertaining the water budget of individual plants and stands (Müller and Bolte 2009). Due to the existing site conditions, the use of different types of lysimeters in investigations around Eberswalde has a long tradition (Table 1).

The Drachenkopf lysimeter

In 1907, the first investigations into the water budget of young trees were conducted with very small-scale lysimeters on Drachenkopf Mountain, in Eberswalde. In 1929, these small-scale lysimeters were replaced by a larger weighable station consisting of three lysimeters, which, in 1954, were supplemented by four additional lysimeters. To our knowledge, the Drachenkopf research station is the oldest lysimeter station used for forest hydrological purposes in the world. The weighable lysimeters have a surface area of one square meter and a depth of 1.5 m.

The large-scale lysimeter at Britz

Forest hydrology research into the effect of different tree species on evaporation and groundwater recharge prompted the construction of large-scale lysimeters at the research station at Britz, near Eberswalde, in 1972 (Müller 1993). After experiences gained from using lysimeters in the past, the large-scale lysimeters were installed at a depth of 5 m, necessary for forest lysimeters, having a surface area of 100 m² (10x10 m) (Figure 1). Nine large-scale lysimeters were set up, and, in 1974, planted with 0.3 ha experimental stands of the tree species Scots pine (3 lysimeters), European beech (2), European larch (2) and Douglas fir (2) at plant spacings corresponding to that applied for each species in forestry practice at the time. The areas surrounding the lysimeters were planted similarly. Thus, the large-scale lysimeters at Britz are unique in Europe in their scale since, although other lysimeters planted with trees have the required area, with depths of 3 m or 3.5 m, they are too shallow.

The weighable lysimeters

Total evaporation, determined with large-scale lysimeters, provides only a general understanding of the water budget in forest stands. The separation of total evaporation into its individual components crown canopy interception, transpiration from trees and evapotranspiration of soils and ground vegetation helps clarify the interaction between the individual components.

In Scots pine ecosystems in the northeastern German lowlands, the ground vegetation and the tree and shrub regeneration represent a substantial yet, so far, difficult to measure water consumer. Special measuring systems need to be used to ascertain the evapotranspiration of the undergrowth, and hence its specific water consumption separately from transpiration of trees in the stand. Consequently, in 1994, special weighing lysimeters were designed. The new type of lysimeter developed contained an undisturbed soil monolith with sufficient size and weighability, for which the construction of a lysimeter cellar was not necessary. With it, the water budget could be balanced at low cost for different types of applications under open field conditions in the forest. Through the use of special weighing cells, the soil moisture change in the soil monolith and the amount of seepage water discharge could be recorded with an accuracy of 0.1 mm. Firstly, the lysimeters were used to measure the water consumption of ground vegetation with different species compositions. The current investigations should look into the influence of drought on the transpiration and young forest tree growth under changing climatic conditions (frequency of extreme summers) more intensively.

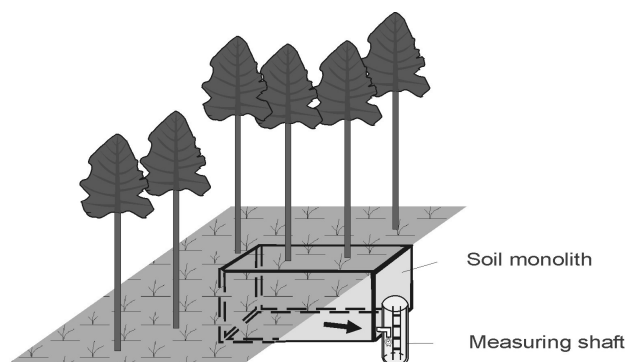


Figure 1. Diagram of a large-scale lysimeter planted with trees.

Results

The investigations at the Britz **large-scale lysimeter station** showed that tree species have an important effect on seepage under forests. The effect of differences in vegetation structure at different growth stages in a Scots pine forest, a European beech forest and a mature mixed stand with Scots pine and European beech on the amount of seepage and evaporation is shown in Figure 2. In the Scots pine stand, total evaporation increases rapidly with growth whereas seepage declines. In the polewood stage, total evaporation is about 100% so that seepage is largely absent. Scots pine growth culminates at this age, and thus the transpiration rates are high (about 60% of the annual precipitation) and, as a consequence of the dense crown cover, interception losses are also high (about 40%) (Müller 2002, 2005). The natural reduction in tree numbers and thinnings cause transpiration and interception to decline gradually, and the seepage percentage increases. However, the proportion of evapotranspiration from the ground vegetation increases relatively strongly due to the opening up of the canopy (Müller *et al.* 1998).

In the European beech stand, evaporation also increases quickly with stand growth, and, in the polewood stage, attains values of almost 80% of the annual precipitation. This value remains relatively constant over a long period up to the saw-timber stage, so that steady seepage levels of over 20% of the annual precipitation also are recorded. Transpiration increases slightly with stand growth, and interception declines as a result of the increasing stemflow (it reaches values of ca. 20% of the annual open field precipitation). Due to the low-light regime in closed European beech stands (Emborg 1998), the evaporation from the forest soil is of minor importance. Seepage is higher in European beech stands in all age phases than in Scots pine. Thus, for example, in mature European beech stands, 50 mm more precipitation seeps into the soil substrate than in mature Scots pine stands under comparable soil and weather conditions (Müller 2002, 2005).

Investigations in pine-beech mixed stands of different ages on sandy soil showed that the amount of seepage fell somewhere between that of the pure Scots pine and pure European beech stands depending on forestry operations performed, stocking density and the tree size of European beech (Müller 2007). Measurements of seepage to 5 m depth in the 28-year old pure Scots pine stand growing on the large-scale lysimeter station at Britz, which was underplanted with European beech and sessile oak in 1999, already show improvements in the groundwater recharge as a result of the Scots pine thinning.

The **weighable lysimeters** were installed in Scots pine stands with a typical ground cover in the northeastern lowlands to determine the water consumption of these ground vegetation types. The typical ground cover consisted of wood small-reed (*Calamagrostis epigejos*), wavy hair grass (*Deschampsia flexuosa*), wavy hair grass/raspberry (*Deschampsia flexuosa* / *Rubus idaeus*) and blueberry (*Vaccinium myrtillus*). Investigations showed that evapotranspiration increased with increasing grass cover. The low shrub layer consumed less water. Thus, closed wood small-reed cover consumed more than one third, and the wavy hair grass almost 30% of the annual precipitation of 620 mm. Where a low shrub layer was present, the evaporation from the wavy hair grass/raspberry layer, a little more than 25%, and the blueberry/wavy hair grass layer, with almost 20% of the annual precipitation, was sometimes distinctly lower than the pure grass cover. In addition to the evaporation from the ground vegetation layer, for which the annual sum varied, the seasonal development

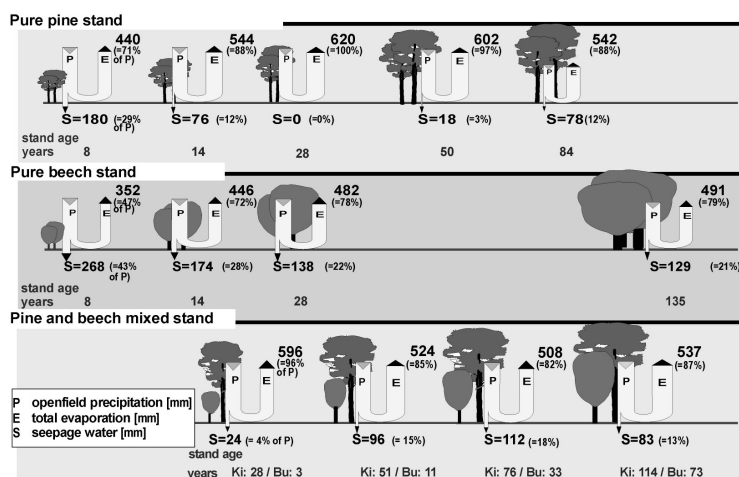


Figure 2. Influence of vegetation structures of Scots pine and European beech at different growth stages on the water budget parameters, evaporation and seepage - (Finowtaler sandy brown earth, 620 mm annual precipitation).

of evapotranspiration during the growing season is also ecologically meaningful. In water limiting periods, the higher water consumption by grass cover leads to a reduction in the amount of plant available soil water, enhancing the water limitation for trees, and thereby impacting upon tree growth (Müller *et al.* 1998). The composition and cover of the ground vegetation influence considerably the amount of water consumed by trees.

Conclusion

Often a major problem of hydrological investigations in different types of ecosystems is the dissimilar conditions, or inability to control sufficiently the environmental conditions in the study sites. Thus, the effects of the parameters of interest may be blurred or false in the results. If one aims to determine the effect of the vegetation on hydrology in the unconsolidated rock substrate, then lysimeter measurements are appropriate for excluding conditions, which are not relevant. Assuming the lysimeters were constructed correctly and adequate in size, they can also be applied for forest ecosystems. Only by considering the special features of the forest structure can one accurately evaluate the hydro-ecological effects. Thus, with the assistance of large-scale lysimeters, the influence of tree species on seepage and evaporation in mature stands can be quantified. It shows that the crown canopy structure considerably influences the amount of seepage and the distribution of the precipitation in the stand as it affects the soil water availability. Total evaporation provides only a general understanding of the water budget in forest stands. The separation of total evaporation into its individual components leads to more meaningful explanations of the interactions between the compartments. During the growing season, the water consumption of the individual vegetation layers is important in the assessment of possible occurrence of water stress.

The main advantage of lysimeter techniques is the opportunity to balance energy and nutrient flows at a high temporal resolution under carefully differentiated conditions. This makes the lysimeter increasingly more interesting for both scientific and practical applications in very different disciplines. Due to their innovative measurement techniques, e.g. weighing cells for determining moisture changes and seepage flows as well as soil moisture sensors and tensiometers for observing seepage water movement, lysimeters are an important instrument for the parameterisation of process models for modelling energy and nutrient cycling. This also applies to forest hydrology research. Lysimeters are indispensable in investigations of water consumption of small forest trees of different origin in the face of increasingly limiting water resources arising from climate change.

References

- BMELV (2008) Bundeswaldinventur² - alle Ergebnisse und Berichte. Online-Dokument unter www.bundeswaldinventur.de.
- Emborg J (1998) Understorey light conditions and regeneration with respect to the structural dynamics of a near-natural deciduous forest in Denmark. *Forest Ecology and Management* **106**, 83-95.
- Müller J (1993) Die Großlysimeteranlage Britz (bei Eberswalde). *Mitteilungen der Deutschen Bodenkundlichen Gesellschaft, Göttingen* **71**, 18-19.
- Müller J (2002) Wirkungszusammenhänge zwischen Vegetationsstrukturen und hydrologischen Prozessen in Wäldern und Forsten. In 'Ökologie und Vegetation der Wälder Nordostdeutschlands' (Ed S Anders) pp. 99-122. (Oberwinter: Verlag Dr. Kessel).
- Müller J (2005) 30 Jahre forsthydrologische Forschung auf der Großlysimeteranlage in Britz – Zielstellung und Ergebnisse. Tagungsband der 11. Gumpensteiner Lysimetertagung Lysimetrie im Netzwerk der Dynamik von Ökosystemen“ am 5. und 6. April 2005 pp. 29-32. (Raumberg-Gumpenstein).
- Müller J (2007) Forestry and limited water budget in the Northeast German Lowlands – consequences for the choice of tree species and forest management. In 'Progress in Hydro Science and Engineering, the Role of Forests and Forest Management in the Water Cycle, Contributions to the Sino-German Symposium 27-30 November 2006'. (Dresden: Dresden Water Center).
- Müller J, Bolte A (2009) The use of lysimeters in forest hydrology research in north-east Germany. *Landbauforschung-vTI Agriculture and Forestry Research* **59**, 1-10.
- Müller J, Bolte A, Beck W, Anders S (1998) Bodenvegetation und Wasserhaushalt von Kiefernforstökosystemen (*Pinus sylvestris* L.). *Verh Ges Ökol Berlin* **28**, 407-414.
- Schröter, D; Zebisch, M; Grothmann, T (2005) 'Climate change in Germany - vulnerability and adaptation of climate-sensitive sectors. Klimastatusbericht, Report on the State of the Climate'. Deutscher Wetterdienst. (German Meteorological Service: Offenbach).

Form of nitrogen leaching from dairy cow urine and effectiveness of dicyandiamide: not all soils are equal

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Abstract

Our hypothesis was that soil type and rainfall will influence the effectiveness of the nitrification inhibitor dicyandiamide (DCD) in decreasing N leaching from urine patches. Intact soil monolith lysimeters (50 cm diameter, 70 cm deep) were taken from three contrasting soil-types: silt loam, clay and sand. The lysimeters were irrigated to achieve either the average annual rainfall for the lysimeter site (1100 mm/year) or twice this amount. Urine with and without DCD was applied in late May (with a repeat application of DCD in July). Nitrogen leaching was measured through to December 2009. The movement of soluble N behaved differently between the three soils. Large amounts of urea were measured in the first drainage events from the clay, suggesting macropore flow. Large amounts of ammonium was leached from the sand (c. 32% of the total mineral N leached), possibly due to a low cation exchange capacity of the soil. DCD was effective in decreasing nitrate leaching from the silt (61%) and clay (36%) soils (as an average of both rainfall regimes), but not from the sand. This experiment suggests that DCD performance can be affected by soil-type, and that losses of soluble forms of N other than nitrate can also be significant on some soils.

Key Words

Nitrate leaching, nitrification inhibitor, soil-type, ammonium, urea.

Introduction

Nitrate leaching losses from intensively grazed pasture can be large because urine patches provide large nitrogen (N) loadings that exceed the pasture's capacity to take up N (Ledgard 2001). In addition to significant NO₃-N leaching, in some soils and climatic conditions, NH₄-N and organic-N (mainly as urea) can be leached from the soil profile as a result of bypass flow following urination (Wachendorf *et al.* 2005; Menneer *et al.* 2008). The use of the nitrification inhibitor dicyandiamide (DCD) is considered in New Zealand pastoral systems to be a technology that can decrease leaching of NO₃ and emissions of N₂O derived from urinary-N (Monaghan *et al.* 2007). Given the potential for its widespread use in pastoral agriculture, we compared the effectiveness of DCD on contrasting soils and under contrasting rainfall regimes using soil monolith lysimeters.

Methods

Soil-types

Sixteen intact soil monolith lysimeters (50 cm diameter by 70 cm deep) were collected from three regions in the North Island of New Zealand to provide a contrast in soil-types: a silt loam (Typic Orthic Allophanic Soil; Hewitt 1993); a slowly draining clay soil (Gleyed clay alluvial fulvi-appodic Soil; Hewitt 1993); and a free draining sand (Buried-allophanic Orthic Pumice soil; Hewitt 1993). Measured soil properties are presented in Table 1.

Table 1. Measured chemical (0-7.5 cm) and physical (0-15, 15-30 cm) soil properties.

	Soil-type 'Clay'	'Silt loam'	'Sand'
pH ^a	5.9	5.9	5.7
Organic Carbon (mg C/g)	9.6	6.5	10.7
Total N (mg N/g)	0.86	0.56	0.65
CEC ^b (cmol/ kg)	31	22	15
Base saturation (%)	78	53	41
Sand-silt-clay 0-15 cm (%)	4-37-59	31-47-22	66-25-9
Sand-silt-clay 30-50 cm (%)	2-21-77	42-57-1	69-26-5

^a Measured at 1:2.1 air-dried soil:water ratio. ^b cation exchange capacity

The pastures at all locations were a permanent mixture of predominately perennial ryegrass (*Lolium perenne* L.) and white clover (*Trifolium repens* L.) and had been under a regular cutting regime for at least 4 months prior to collection of the lysimeters to avoid the influence of excreta inputs.

Lysimeter collection and installation

The lysimeters were extracted using the method described by Menneer *et al.* (2008). Briefly, a metal cylinder casing with an internal cutting ring was pushed into the soil, the soil monolith was then undercut, lifted from the soil and a steel base plate with a central drainage hole was secured to the bottom of each lysimeter. The small gap between the soil monolith and the cylinder wall was sealed using petroleum jelly to prevent edge-flow effects (Cameron *et al.* 1992). The lysimeters were carefully transported to minimise soil disturbance and were installed at ground level at the AgResearch Ruakura Research Centre lysimeter facility, Hamilton. All lysimeters were watered to saturation and allowed to drain to field capacity, and were then exposed to natural weather conditions during April before application of treatments in May.

Experimental design and treatments

Treatments were three soil types (as described above), two rainfall regimes (annual average and twice the amount for the experimental site in the Waikato region) and \pm DCD application, in a randomised block experimental design (4 replicates). Simulated rainfall was applied (if necessary) regularly and in small doses to the appropriate lysimeters as spray irrigation to meet the targeted annual rainfall regime (1100 and 2200 mm/year). Total water inputs (rainfall + irrigation) for each rainfall regime were based on the 30-year long-term average for the Waikato region.

Dairy cow urine was collected from dairy heifers and urea-N was added to adjust the final total N concentration to 10.0 g/l. This was then applied in a single application at an equivalent rate of 1000 kg N/ha in late May to simulate a dairy cow urine deposition. DCD was applied (10 kg/ha) to the designated lysimeters as a fine suspension spray following urine application and re-applied in mid-July. In the urine-only treatments, an equivalent volume of distilled water was sprayed onto each lysimeter to maintain the same moisture input to all lysimeters. Following treatment application, all lysimeters received 10 mm of spray irrigation to ensure the DCD was in contact with the soil.

Determination of N leaching losses

Leachates were collected from the lysimeters when drainage occurred, or weekly, for chemical analysis. Leachate samples were analysed for NO₃-N and NH₄-N using a Skalar SAN++ segmented auto flow analyser (Skalar Analytical B.V., Breda, Netherlands). Urea in leachate was determined colorimetrically (Douglas and Bremner 1970).

Results

Rainfall and drainage

Here, we report the first 7 months of the experiment from the application of the urine (May 22) through to the end of December. This covers the main drainage period. During this period there was 770 mm rainfall and an average of 445 and 985 mm drainage from the 'average' and 'supplemented' rainfall regimes, respectively.

Nitrate leaching

The amount of nitrate leached during the entire drainage followed the expected relationship with soil-type: sand > silt loam > clay (as an average of both rainfall regimes), Table 2. There were highly significant interactions ($P < 0.001$) for the amounts of NO₃-N leached after urine application between soil-type and rainfall (data not shown), and between soil-type and DCD application.

Table 2. Effect of soil-type and DCD application on nitrate-N leached (kg NO₃-N/ha), as a mean of the two rainfall regimes imposed on the experiment.

Soil-type	Urine treatment	
	Control	+DCD
Silt loam	312	131
Clay	142	77
Sand	259	272
LSD (P=0.05)	54.6	

The DCD was ineffective in the sand. Decreases in NO₃-N leaching resulting from application of DCD were 58% and, 46% for the silt and clay soils, respectively (as an average of the two rainfall regimes). Surprisingly, there was no significant interaction between DCD application and rainfall. This is counter intuitive and the overall result may have been affected by the ineffectiveness of the DCD in decreasing NO₃-N leaching on the sand. Certainly, for the other two soils, DCD appeared to be less effective at the higher rainfall regime: there was a trend for a decrease in effectiveness from 69% to 54% for the silt loam and from 50% to 22% on the clay when comparing average and supplemented rainfall regimes.

Ammonium leaching

DCD application had no effect on NH₄-N losses from any of these soils. However, there was a highly (P<0.001) significant effect of soil-type and rainfall (Table 3). For the silt loam and clay soils, much of this NH₄-N was present in the early drainage; this suggests macropore flow on these two soils. However, for the sand, the concentration profiles show a smooth leaching curve indicative of 'piston flow' (Figure 1).

Table 3. Effect of soil-type and rainfall regime on ammonium-N leached (kg NH₄-N/ha), as a mean of control and DCD treatments. Data were square root transformed.

Soil-type	Rainfall regime		Level of significance
	Average	Supplemented	
Silt loam	4	12	ns
Clay	29	63	**
Sand	68	204	***
Average LSD (P=0.05)	24.4		

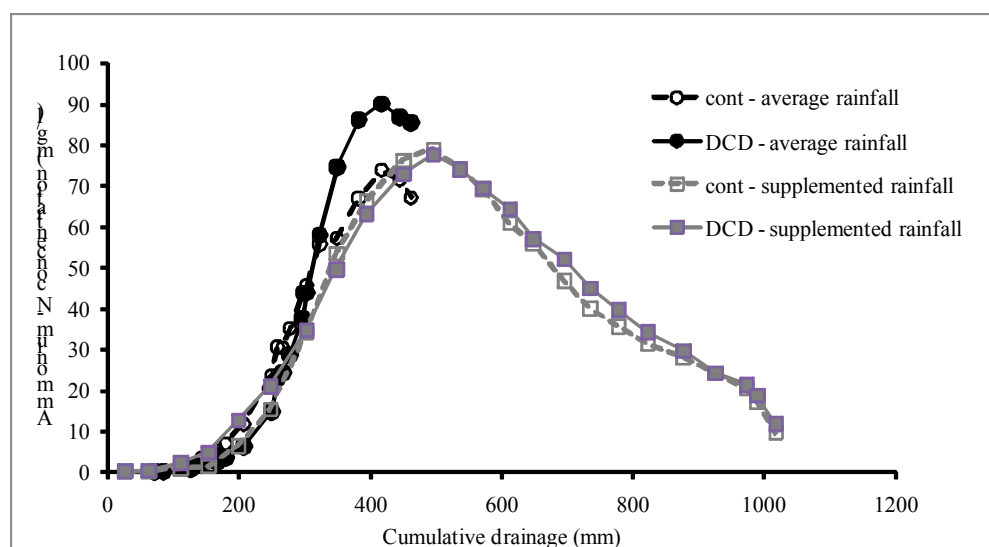


Figure 1. Concentration of NH₄-N in the drainage from the sand soil lysimeters

Urea leaching

There was a highly significant effect (P<0.001) of soil-type on loss of urea in drainage water, but no effect of rainfall regime or DCD application. Urea was measured in the first two drainage events and none was found in the leachate samples after that. This suggests the cause was initial macropore flow, with most urea lost from the more structured soils. Measured losses were: 123, 22 and 5 kg urea-N/ha for the clay, silt and sand soils, respectively.

Discussion

The contrasting textures and structure of these three soils affected the transport of urine-N, and its form, to 70 cm depth in the lysimeters. This has implications for the effectiveness of DCD in decreasing soluble N loss from urine patches.

DCD was effective on two of the three soils in decreasing nitrate leaching. The effectiveness of DCD has been reported before (Di and Cameron 2007; Monaghan *et al.* 2007) and, in some circumstances, offers potential as a practical mitigation technique in decreasing nitrate leaching from grazed pastures. However, a significant proportion of the applied N was leached as urea immediately after application in the clay soil, probably due to its highly prismatic structure. This has been recognised in some situations (Silva *et al.*

2007), but its immediacy means that there is a smaller pool of ammonium for any DCD to act upon in the soil surface.

Ammonium-N losses also occurred but were dependent on soil-type and rainfall. DCD had no significant effect on $\text{NH}_4\text{-N}$ leaching, even though the mode of action is to hold N as $\text{NH}_4\text{-N}$ in the soil. On the silt and the clay soils, the $\text{NH}_4\text{-N}$ concentration profiles with the drainage suggest that losses were due to bypass flow and rapid movement to depth. However, in contrast, the sand soil leached substantial amounts of $\text{NH}_4\text{-N}$ via piston flow (Figure 1), suggesting that the soil was unable to bind the ammonium. Qian and Cai (2007) found similarly large $\text{NH}_4\text{-N}$ leaching from soils with low cation exchange capacity and low base saturation. This is one possible explanation for the $\text{NH}_4\text{-N}$ leaching from the soil (Table 1), though further investigation is warranted. This downward movement of $\text{NH}_4\text{-N}$ may also explain why the DCD was ineffective on this soil-type.

Conclusion

DCD decreased leaching of nitrate from the silt loam and clay soils tested in this experiment. Further benefit may be observed in the second winter under the average rainfall regime because the full elution curve was not completed on these soils in the first winter.

As well as nitrate, this experiment shows that losses of other forms of soluble N can also be large. Further work is required to explain the lack of DCD effect on the sand soil and the large $\text{NH}_4\text{-N}$ leaching losses from this soil in this experiment. The relationship between the loss processes and soil-types needs to be fully understood so that a realistic assessment of the likely effect of DCD on decreasing soluble N losses across a range of situations can be evaluated.

Acknowledgement

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References

- Cameron KC, Smith NP, McLay CDA, Fraser PM, McPherson RJ, Harrison DF, Harbottle P (1992). Lysimeters without edge-flow: an improved design and sampling procedure. *Soil Science Society of America Journal* **56**, 1625-1628.
- Di HJ, Cameron KC (2007). Nitrate leaching losses and pasture yields as affected by different rates of animal urine nitrogen returns and application of a nitrification inhibitor - a lysimeter study. *Nutrient Cycling in Agroecosystems* **79**, 281-290.
- Hewitt AE (1993) Methods and rationale of the New Zealand Soil Classification. Landcare Research Science Series No 2, pp.71.
- Ledgard S (2001) Nitrogen cycling in low input legume-based agriculture, with emphasis on legume/grass pastures. *Plant and Soil* **228**, 43-59
- Menner J, Ledgard S, Sprosen M (2008) Soil N process inhibitors alter nitrogen leaching dynamics in a pumice soil. *Australian Journal of Soil Research* **46**, 323-331.
- Monaghan RM, Hedley MJ, Di HJ, McDowell RW, Cameron KC, Ledgard SF (2007) Nutrient management in New Zealand pastures - recent developments and future issues. *New Zealand Journal of Agricultural Research* **50**, 181-201.
- Qian C, Cai Z (2007). Leaching of nitrogen from subtropical soils as affected by nitrification potential and base cations. *Plant and Soil* **300**, 197-205.
- Silva RG, Cameron KC, Di HJ, Smith NP, Buchan GD (2000) Effect of macropore flow on the transport of surface-applied cow urine through a soil profile. *Australian Journal of Soil Research* **38**, 13-23.
- Wachendorf C, Taube F, Wachendorf M (2005). Nitrogen leaching from ^{15}N labelled cow urine and dung applied to grassland on a sandy soil. *Nutrient Cycling in Agroecosystems* **73**, 89-100.

Impact of soil organic carbon content on soil filtering capacity solutes

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Abstract

Our objective was to study how soil organic carbon (SOC) influences the solute transport. To monitor the water and solution movement in soil, anion bromide has been used as a tracer. We were interested in the transport process of nitrate, because of its relevance concerning the issue of nitrogen contamination of groundwater. The study investigated soils under two different types of land use with different carbon contents. The first land use was a pair of soils under apple orchards. The second land use was permanent pasture grazed by sheep. Generally, soil properties improve with soil carbon management. This study showed the converse for the aspect of surface applied solutes under conditions where there would be the likelihood of surface ponding of water.

Key Words

Soil organic carbon, nitrate, drainage-flux meters and water.

Introduction

Agriculture and horticulture systems in New Zealand are managed according to the guidelines of either organic or integrated fruit production. In previous studies those systems have been compared in various aspects, one is the 'soil carbon management' what is defined as "land management practices that maintain or increase SOC" (Deurer *et al.* 2007). The study focused on the impact of soil carbon management on the soil filtering capacity of surface applied inert solutes. Such an inert solute is the nutrient nitrogen, which is essential for the growth of many plant species. Excess nitrogen becomes a problem if it leaches, in the form of nitrate, through the soil into the groundwater or the neighbouring rivers and lakes. Therefore it is important to know which soil characteristics are affected by nutrient leaching and what are the relevant processes. There are two kinds of nitrate in the soil, one is mineralised nitrogen from organic matter, and other is surface applied fertilizer. In this study we focused on the affect of SOC on the transport of surface applied solute.

Hypothesis 1: Due to the higher macro-porosity we presumed that the organic orchard soils would have a higher leakiness than the integrated orchard soil. Preceding studies have found that the soils aggregate size fraction from the 'non-camp' and 'camp' site were hydrophobic and have lost some capacity to rapidly absorb applied solutions (Aslam *et al.* 2009). Based on several other studies, the SOC content is positively correlated with the degree of soil water repellency. It has also been determined that the macro-aggregates from the 'non-camp' site were significantly less hydrophobic than from the 'camp' site. Previous studies have reported that water-repellent zones cause preferential flow which is defined as all phenomena where water and solutes move along certain pathways, while bypassing a fraction of the porous matrix' (Hendrickx and Flury 2001). In other words, preferential flow refers to the uneven and often rapid movement of solutes through porous media, characterized by regions of enhanced flow such as wormholes, root holes and cracks. Hypothesis 2: Based on this knowledge of water repellency we presumed that the 'camp' site with 30% more SOC would have a lower solute filtering capacity than the 'non-camp' site.

Methods

Sampling Sites

Intact soil cores (30 cm x 10 cm) were collected from four sites. The first two sites were on rows on neighbouring orchards in Hawke's Bay, New Zealand. Both soils had the same loam texture but different carbon management practises. One is an organic apple orchard system managed according to the BIO-GRO standards (<http://www.biogro.co.nz>) with regularly added compost. The other system is an integrated orchard managed according to the standards of integrated fruit production. A 0.5-m wide strip under the trees was

kept bare by regular herbicide applications. In the organic orchard the trees were grassed and regularly mowed when necessary while the strips in the integrated orchard were kept vegetation-free. In the organic system green-waste from the orchard has been applied to the topsoil once a year whereas in the conventional orchard the pruning and leaf fall were the only regular organic manure. After 12 years the topsoil (top 10 cm) of the organic orchard had with 38.8 kg SOC/m² about 30% more SOC sequestered than those of the integrated orchard with 2.6 kg SOC/m². (Aslam *et al.* 2009) The other two sites were on a sheep pasture with a loam texture like on the apple orchards. Due to the sheep habits, the paddock could be separated into areas. One area was too steep for the sheep to rest on, so was the main grazing region. These areas are called “Non-Camp” sites. The steep area was intercepted with relative even spots, thus the sheep used those areas to rest during the night. Such areas are called ‘camp-sites’ and known to accumulate sheep manure. As a consequence the topsoil (top 10 cm) of the ‘camp-sites’ sequester 8.7kg SOC/m², 30% more SOS compared to the non-camp site with 6.3 kg/cm².

Drainage flux-meters

To monitor the drainage and leaching we used drainage-flux meters. The device enables to collect and measure the volume of the drainage water. On the top of the drainage flux meter is a column which is used to collect undisturbed soil samples and also prevents the sideway flow of water and solution during the trial. The column containing the soil is “bolted” on two other assemblies. One is collecting the drainage and the other one contains a funnel, a wick, and the tipping spoon (drop-counting mechanism). To prevent soil from entering the funnel, a thin layer of diatomaceous earth is placed above the wick. The spoon under the wick is connected to a data-logger and quantifies the volume of water. To calibrate the tipping spoon a known amount of water is injected via calibration tub that ends right above the spoon. After the drainage-flux meters were loaded with the undisturbed soil samples of the study site, they were assembled under an irrigation system. For each soil category we had three replications.

The Tracer Bromide

The tracer bromide has been used to monitor the water and solution movement in the soil. Bromide is widely used as relatively conservative tracer in hydrological and biogeochemical studies, having the advantage of a very low natural background concentration in the soil (Flury and Papritz 1993). At the beginning of the trial 250 mg of potassium bromide mixed in 20g of sand was added on the top of the drainage-flux assembled meters. The flux meters have been irrigated during the day but were not irrigated at night. In the beginning the drainage was sucked out of the solution collector 3-4 times a day. Later on it was less often, because we presumed that the major ratio of bromide was already leached out. The concentration of bromide in the effluent was measured with an ion-chromatograph at Massey University, Palmerston North, New Zealand.

Results

Drainage

The water flow of the organic and integrated orchard soils, (30% different in SOC content) shows no real difference. Whereas the camp site with 30% more SOC than the non-camp site has an apparently higher drainage. Because of the different utilisation of orchards and paddock the comparisons in terms of the SOC content is suitable to only a limited extent. However, due to the same texture but higher drainage rate of the pasture soils we presume a higher macro-porosity of the paddock soil compared to the orchard soil.

Breakthrough curves

The pasture and the orchard soils come from a different land use and hence the curves look different. In the effluent of the both orchard soils the bromide appears later and in a lower concentration compared to the pasture soil. This is likely determined by higher macro-porosity of the paddock soils as hypothesised in the introduction.

An unexpected irregular concentration time trend for both orchard soils, whereas this is not the case for the pasture soils. It is conspicuous that the effluents of organic and integrated soils have a concentration decline at the same time. On closer inspection, the low concentration was measured in water samples which were taken in the morning, from the first effluent after an irrigation stop during the night. This indicates that the fluctuating concentration is caused by flow-interruption where evaporation occurs, but diffusion continues.

Earlier studies about interrupted flow have shown that the solute transport is influenced by micro-pore diffusion. The degree to which flow interruption might influence solute transport depends on the factors such

as the degree of heterogeneity, the length and the timing of interruption, and the characteristic time of diffusion, which is a function of the magnitude of the diffusion coefficient and the concentration gradient (Brusseau *et al.* 1996). Hence, we can assume that the relative constant curves of the pasture soils is mainly caused by a more homogeneous soil structure compared to the orchard soil structure. Additionally it has been said that the concentration gradient influences the degree of the non-ideal transport affected by flow-interruption. The bromide transfer through the pasture soil is so rapid that already after a short time the concentration in the effluent is quite low. Therefore the concentration gradient inside the soil is also low, this may be a secondary reason for the more consistent curve of the pasture compared to the orchard soil.

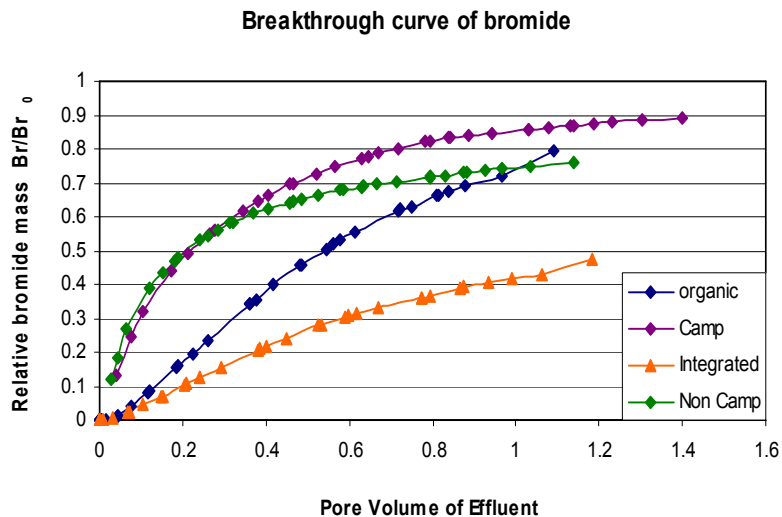


Figure 1. The Graph shows the bromide breakthrough curves for water-unsaturated soils. Relative bromide mass is the ratio of added bromide measured in the effluent. Pore volume is the ratio of the volume of effluent to the volume of fluid in the soil sample.

The breakthrough curve of the pastures rises clearly earlier and steeper compared to the orchard curves (Figure 1). Even though the pasture and orchard soils have different textures, the breakthrough curves look like as we would expect. Given that the water flow through the orchard soils is less rapid than in the pasture soils, we can explain the later appearance bromide with more matrix exchange of the solute.

In case of the orchard soils, the breakthrough curves show a continuous rise of recovered bromide, whereas a consistently higher amount of bromide is recovered in the effluent of the organic orchard soil. With a pore volume of 0.7, 45% of the added bromide had passed through the organic soil and approximately 35% from the integrated soil. The t-test showed that this is significantly different ($P < 0.05$).

The major reason for higher mobility of bromide in the organic orchard compared to the integrated orchard is likely the soil structure, with higher macro porosity caused by the increased SOC content. Due to the higher surface-to-volume ratio and connectedness of micro-pores, the interaction between solute and soil aggregates in the micro-pores is higher than in the macro-pores. Consequently we found that the SOC content is positive correlated to the leakiness of the soil for surface applied solutes.

In the case of ‘camp’ and ‘non-camp’ soils there is no difference in the beginning of the breakthrough curves. After a pore volume of 0.3, approximately 60% of bromide was recovered. Considering the fact that the soils aggregate fraction from the ‘non-camp’ and ‘camp’ site were hydrophobic and had lost some of their capacity to wet up (Aslam *et al.* 2009) we assume that the rapid bromide transport was found because of preferential flow, where the solution moves without exchange into the aggregates through the soil. Later, the breakthrough curve of the ‘camp’ site rises more than the ‘non-camp’ curve. In the end 90% of added bromide was retrieved from the ‘camp’ site and 75% bromide from the ‘non-camp’ site. We could not find a significant difference with the t-test, because we had in the end just 2 replicates for the non camp. Although the t-test has not showed a significant difference, it is most likely that the camp and non-camp have a different filtering capacity. Whether the rise of the ‘camp’ and ‘non-camp’ curves is different, both have the trend to increase much less than in the beginning, thus it seems to be an asymptotic expansion. The reason for the less rapid transport of bromide later on could be that the micro-pores and soil aggregates started to absorb water, hence the ratio of preferential flow (Clothier *et al.* 2008) was reduced.

Pertaining to the difference of the two pastures, we found that later on the solute filtering capacity of the 'non-camp' soil was higher compared to the 'camp' soil as the 'camp' site was more hydrophobic than the 'non-camp' site. Consequently we found, as with the results of the orchards, a higher filtering capacity for surface applied solutes for the soil with less SOC.

Conclusion

We studied how the soil's organic carbon content influences the soil's filtering capacity, with the goal of mimicking the leaching of surface-applied nitrate with an anion tracer. We found on two pairs of soils that the filtering capacity of the tracer was less in the soil with a higher SOC content in the topsoil. This consequently means that surface-applied nitrate would leach faster for the soil with a higher organic carbon content under these conditions where the irrigation rate would likely cause surface ponding of water on the matrix and allow access to the macroporous network. Valuing these results in terms of preferable soil quality and ecosystem service we would come to the conclusion that less soil organic carbon has the advantage of less leakiness for surface applied fertiliser when there is likely to be surface ponding. Considering, however, the nitrate which might be mineralised in the soil, it can be considered that a higher SOC content would increase the soils ability to mineralise nitrate indigenously, because the nitrate mineralisation in the soil aggregates would be positively correlated with the SOC content. Therefore we can hypothesise that there would be an improvement for the filtering capacity of mineralised nitrate, in contrast to the weaker filtering capacity for exogenously applied surface fertilisers that would be affected by a higher SOC content.

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References

- Aslam T, Deurer M, Mueller K, Clothier BE, Rahman A, Northcott G, Ghani A (2009) Does an increase in soil organic carbon improve the filtering capacity of aggregated soils for organic pesticides? – A case study. *Geoderma* **152**, 187 - 193
- Brusseau ML, Hu, Q, Srivastava R (1996) Using flow interruption to identify factors causing nonideal contaminant transport. *J. Contaminant Hydrology* **24**, 205-219
- Clothier BE, Green SR, Deurer M (2008) Preferential flow and transport in soil: progress and prognosis. *European Journal of Soil Science* **59**, 2-13
- Deurer M, Sivakumaran S, Ralle S, Vogeler I, McIvor I, Clothier B, Green S, Bachmann J (2008) A new method to quantify the Impact of soil carbon management on biophysical soil properties: the example of two apple orchard systems in New Zealand. *J. Environ. Qual.* **37**, 915-924.
- Flury M, Papritz A (1993) Bromide in the natural environment: water application. Occurrence and toxicity. *J. Environ. Qual.* **22**, 747–758.
- Hendrickx JMH, Flury M (2001) 'Uniform and preferential flow, mechanisms in the vadose zone, conceptual models of flow and transport in the fractured vadose zone'. (National Research Council, National Academy Press: Washington, DC).

Lysimeter research in Europe – technological developments and research strategies

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Abstract

Exact information about the soil water balance is needed to quantify water and solute transfer within the vadose zone. The monitoring of these fluxes is a big challenge because the results are the basis for answering a couple of questions regarding protection of groundwater, sustainable management of agriculture, mining or set aside industrial areas, reducing leachate loss from landfills or explain the fate of industrial harmful substances. In Europe, the use of direct lysimetry methods for measuring water and solute flows in soils has increased in the recent years. The combination of lysimeter studies with field experiments at different scales opens new possibilities for modelling and management of watersheds. The paper informs about a cutting technology for the undisturbed extraction of a soil monolith at different sites, which is compared to the most frequently used extraction procedures using X-ray tomography. The weighing precision of a 2 m deep lysimeter with a 1 m² cross-sectional area is demonstrated and shows that the direct measurement of dew, fog and rime is possible. New technical developments as well as strategies for further lysimeter research activities will be presented and discussed.

Key Words

Soil hydrology, lysimeter technique, soil monolith extraction, weighing precision, lysimeter development

Introduction

Different lysimeter types are used at research institutes, administration facilities as well as environmental service agencies. In the international literature, the term “lysimeter” is used for different objectives, e.g. suction cups, fluxmeters, etc. (Weihermueller *et al.* 2007). According to our understanding, it belongs to the direct methods to measure water and solute fluxes in soil. The design (required surface and length) depends mainly on the scientific question, the nature of vessel filling (disturbed or undisturbed), the lower boundary, and the location of installation. Small scale heterogeneity of a site will be averaged using a larger base area of the lysimeter. Furthermore, lysimeters with vegetation should represent the natural crop inventory and the maximal root penetration depth should be taken into account. Except for the generation of well defined recurrences of the same soil conditions, it is recommended to fill the lysimeter vessel monolithically. According to our knowledge, a large weighable lysimeter is the best method for obtaining reliable data about seepage water quantity and quality, but it involves significant investment and additional expenses for maintenance. Nevertheless, in Europe the use of direct lysimetry methods for measuring water and solute movement in soils increased in recent years (Lanthaler and Fank 2005). The aim of this paper is to inform about (i) technologies for the undisturbed extraction of a soil monolith at different sites during filling a lysimeter vessel of different sizes, (ii) the high accuracy of the lysimeter weighing technique and (iii) strategies regarding the development and use of lysimeter techniques.

Methods

Soil monolith extraction technology

Minimal disturbance of the soil monolith during extraction and subsequent filling of the lysimeter vessel is of critical importance for establishing flow and transport conditions comparable to natural field conditions. In the past, several methods were used to extract and fill lysimeter vessels vertically - including hand digging, employing sets of trihedral scaffolds with lifting blocks and ballast, or using heavy duty excavators, which could shear and cut large blocks of soil. More recently, technologies have been developed to extract cylindrical soil monoliths by using ramming equipment or screw presses. One of the great disadvantages of the mentioned methods is the compaction or settling of soil that occurs during the “hammering” or “pushing”. For this reason a new technology was developed, which cuts the outline of the soil monolith employing a rotary cutting system (Meissner *et al.* 2007). This procedure should avoid structural damages and substantially reduces the necessary technical expenditure during monolith extraction. The extraction site is only minimally affected, since the forces needed for cutting the soil monolith are small, due to reduced wall friction of the lysimeter vessel. This “cutting” technology has been used successfully for different soil

types (from peat to gravel to sand to clay and including contaminated sites) and for different lysimeter dimensions (surface area 0.1-2 m² and depths of 0.5-3.0 m).

Weighing precision

A key parameter of a lysimeter is its weighing precision – the higher it is, the better the resolution of the weight measurements. A high resolution makes it possible to chart seepage and evapotranspiration over short periods such as hours or less, while a low resolution only allows daily values. Instead of a mechanical weighing system, which is currently the most widely used technology, our new lysimeters are equipped with three shear-stress cells, which are placed on top of aluminium pedestals (Xiao *et al.* 2009). The shear-stress cells produce a current, which is proportional to the load. The current is then transformed into a digital signal using an A/D-converter, which is adjusted to record the mass of the lysimeter vessel with a resolution of 10 g. For routine work, the weight is registered every 10 s and then averaged for intervals of 10 min.

Results

Soil monolith extraction technology

For the evaluation of the different extraction technologies with respect to the potential disturbance of soil structure we applied the different techniques for the same soil type (Eutric Fluvisol). At natural site conditions, soil monoliths with the same size have been extracted with the “hammering”, the “pushing” and the “cutting” technology (Figure 1). The soil structure close to the vessel wall was recorded using X-ray tomography at a resolution of about 0.1 mm. The X-ray tomography images showed that the “hammering” procedure irreversibly influences the structure of the soil monolith; the “pushing” technology reduces the disturbances but is connected with structural damages around the excavation pit. The “cutting” technology influenced only the edge between soil monolith and the lysimeter vessel and reduced damages at the extraction site essentially. There are different cutting devices for the individual size of the lysimeter vessel available.

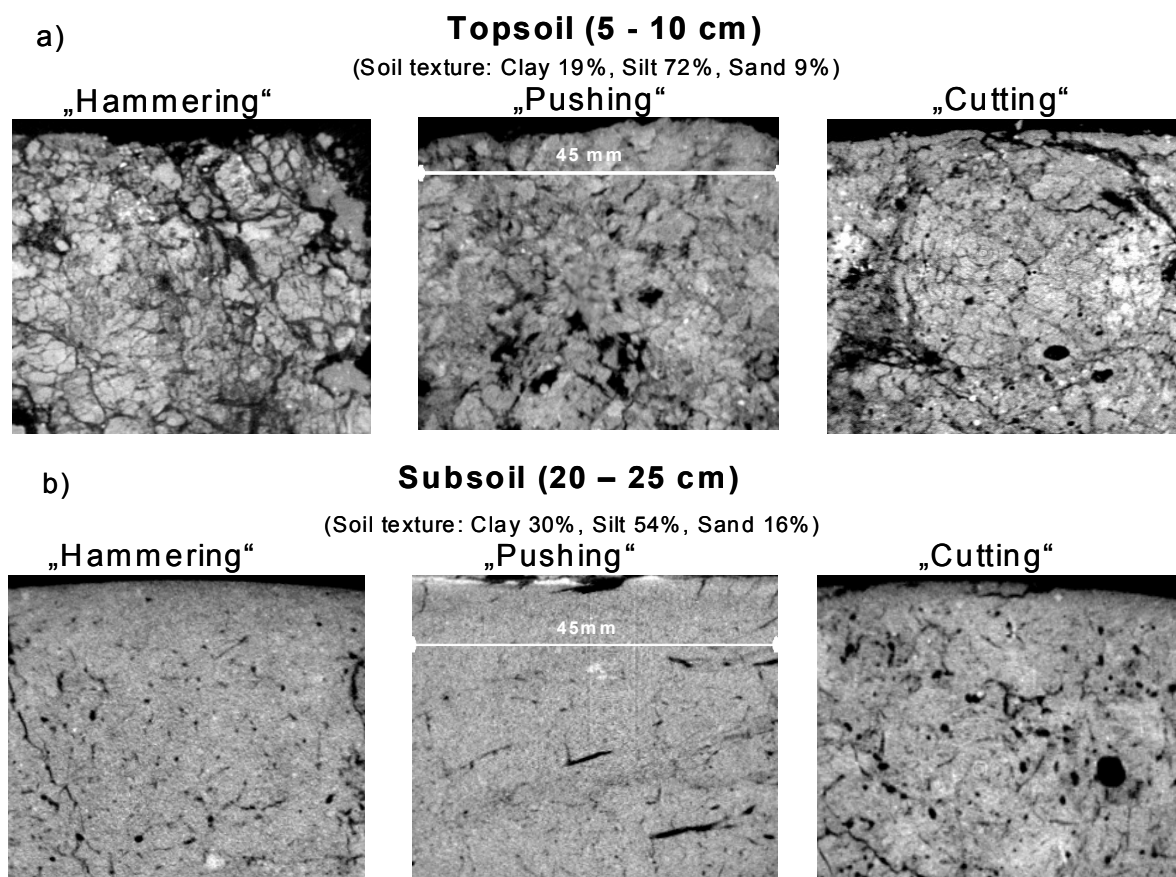


Figure 1. X-ray tomography images during testing of different soil monolith extraction techniques for the soil type „Eutric Fluvisol“ at a floodplain site; a) topsoil, b) subsoil.

Weighing precision

Tests were carried out to determine the weighing precision of a 2 m deep lysimeter with a 1 m² cross-sectional area and a total mass of 3500 to 3850 kg, depending on the soil water content. Weights of 500, 200, 100, 50, 20, and 10 g were placed at the centre of the lysimeter as well as at 10, 23, 55, 77, and 100 cm along two perpendicular lines through the centre of the lysimeter. Mass changes as small as 20 g, which is equivalent here to water gain or loss of 0.02 mm, can be measured with good accuracy and stability under favourable environmental conditions (low wind speed, relatively constant temperature) (Figure 2). This precision does not depend on the position of the weights at the lysimeter where the mass change occurs. This lysimeter type makes it possible to register mass input by dew, fog or rime and it also permits a very accurate calculation of the actual evapotranspiration.

Special experiments with this lysimeter type showed that dewfall makes a notable contribution to the water balance of crops and grass in northern Germany, since it amounted to 5.5 -6.9% of the annual and, several times during the study period, to > 20% of the monthly precipitation. The dewfall study also illustrates that the vegetation cover affects dew formation. There was consistently more dewfall on covered than on bare lysimeters. In addition, dewfall increased with crop growth, reflecting the rising frequency and amount of dewfall on growing crops compared to a continuous grass cover, and then fell again after harvest.

A high-resolution weighing technique enables detailed investigations of the water balance, forming the basis for a highly accurate calculation of the solute balance and for modelling hydrologic processes. Furthermore, the newly developed experimental setup allows a scenario simulation of topical climatic and hydrologic questions, e.g., global warming and its impact on the water and solute balance, the influence of dew, fog and rime on the establishment of a vegetation cover in arid areas or the transport of contaminants during heavy rainfall following severe drying-up of the soil profile.

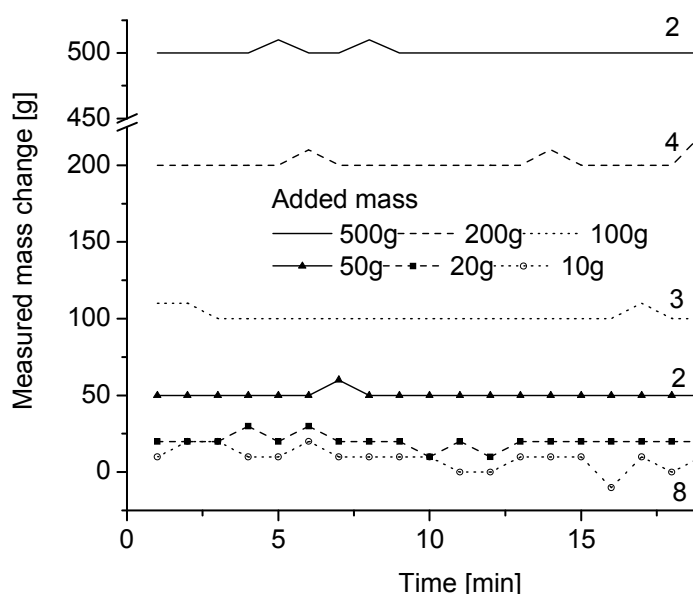


Figure 2. Recorded mass change over a 20 min period after the addition of different weights for the gravitation lysimeter. The values near the lines indicate the number of deviations from the true mass change.

Conclusion

In Europe, lysimeters of various designs are used to quantify diffuse pollution of water resources and to improve modelling and management of watersheds. There is a tendency to develop new lysimeter techniques, especially regarding the extraction of undisturbed soil monoliths of different sizes, the implementation of a high-resolution weighing technology, the development of containerized lysimeter stations as well as specific lysimeter types (groundwater lysimeter, fen lysimeter) and the improvement of technical details as the lower boundary condition and a technology for sinking lysimeters during field work

on the ground (Meissner *et al.* 2008). Gravitation lysimeter vessels are also used to test non-invasive techniques (electrical resistivity tomography –ERT, ground penetrating radar – GPR) to characterize water and solute fluxes in soils. Interesting is also a new retrieval technology for intact soil monoliths from lysimeter vessels which allows the immediate dissection of the soil column into slices and its investigation. The new extraction techniques opens new avenues for a direct comparison of state variables and fluxes measured in lysimeters with those measured directly in the field. This is because after the extraction of the monolith a cylindrical cavity remains where the surrounding soil is not affected by the sampling procedure. The walls of this cavity can be analyzed to get valuable information about the structure and layering of the soil inside the lysimeter. Moreover, this cavity can be equipped with equivalent sensors systems as the lysimeter. This monitoring concept is actually realized within the “TERENO” (TERrestrial ENvironmental Observatories) project at the UFZ. “TERENO” is a research initiative of the Helmholtz Association with the aim to establish observation platforms in different climate and management sensitive regions of Germany and to investigate the behaviour of terrestrial systems in response to changing environmental conditions.

References

- Lanthaler C, Fank J (2005) Lysimeter stations and soil hydrological measuring sites in Europe – results of a 2004 survey. In ‘Proceedings of the Eleventh Lysimeter Symposium, Raumberg- Gumpenstein’, pp. 19-24 (Ed. A. Sonnleitner) (Austrian Lysimeter Research Group:Gumpenstein).
- Meissner R, Seeger J, Rupp H, Seyfarth M, Borg H (2007) Measurement of dew, fog, and rime with a high-precision gravitation lysimeter. *Journal of Plant Nutrition and Soil Science* **170**, 335-344.
- Meissner R, Rupp H, Seyfarth M (2008) Advances in out door lysimeter techniques. *Water, Air and Soil Pollution: Focus* **8**, 217-225.
- Weihermueller L, Siemens J, Deurer M, Knoblauch S, Rupp H, Goettlein A, Puetz T (2007) In situ soil water extraction: A review. *Journal of Environmental Quality* **36**, 1735-1748.
- Xiao H, Meissner R, Seeger J, Rupp H, Borg H (2009) Testing the precision of a weighable gravitation lysimeter. *Journal of Plant Nutrition and Soil Science* **172**, 194-200.

Lysimeter Soil Retriever (LSR)-A tool for investigation on heterogeneity of the migration and structural changes

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Abstract

Generally research fields of lysimeter studies scheduled as long term experiments. In the course of the studies, the lysimeters act more or less as a “black box”. Usually the soil material is identified and analyzed at the beginning of the experiments, but there is also a strong need to analyze the soil without disturbance of the soil structure after the experiments in order to obtain information about spatial and structural changes within the soil profile. The new technique of the Lysimeter Soil Retriever (Reth *et al.* 2006; 2007; Seyfarth and Reth 2008) for the first time enables studies on the heterogeneous migration of percolating water, and changes of soil structure as well as soil organic matter (SOM) and biomass distribution, as well as the distribution of mycorrhiza and microbes in different depths on intact soil profiles. The main target by using the LSR is the preparation of an intact soil monolith from the field lysimeter and the immediate dissection into slices to enable a direct sampling of its soil environment at several depths. Distribution and composition of SOM, pH-values, soil porosity, as well as degradation of PAH were only a few parameters, which are determined at the different soil depths. In this presentation we give some examples for the different application of the LSR and the advantage for the experiments:

Introduction

Objectives of the retrieving the lysimeter soil:

- Compare chemical and biological soil functions, which are affected in long term experiments
- Clarify the lysimeter vessel's effect on the soil (e.g. side effects)
- Measure changes in the top soil, e.g. packing, root distribution, aeration, water conductance, biological activities
- Quantify changes in soil physical parameters within long term experiments that used lysimeters as well the reference site

Measurements

Example 1: In a lysimeter study, the impact of elevated ozone concentration and root pathogen infection on the plant-soil-system of young beech (*Fagus sylvatica*) trees was assessed down to 2 m depth with a high vertical resolution. Due to the accurate sectioning of the soil monoliths a very dense and intensive soil sampling was possible. Fine root biomass below 1 m depth was significantly reduced under elevated ozone while fine root biomass increased in soil deeper than 20 cm when trees were infected with the pathogen (Figure 1). As the whole soil space of 8 lysimeters could be sampled, precise spatial information were obtained about the rapid formation of SOM depth gradients within the duration of the experiment (Figure 2).

Example 2: After the investigation on the mobilization of polycyclic aromatic hydrocarbons (PAH) by the seepage water, the lysimeter soil was retrieved. Investigations on the microbiological degradation of the PAH were possible in the whole soil monolith. From spring 2004 to October 2006 a lysimeter (1 m² x 1.40 m depth) installed on the test area Wielenbach was investigated on the mobilization of polycyclic aromatic hydrocarbons (PAH) by the seepage water. The soil originated from a sleeper factory of the Deutsche Bahn at Kirchsee on (Oberbayern, Germany) was contaminated by PAH with a concentration of 16 mg/kg soil. The slices were analyzed to get information about the heterogeneity of the migration of the percolating water.

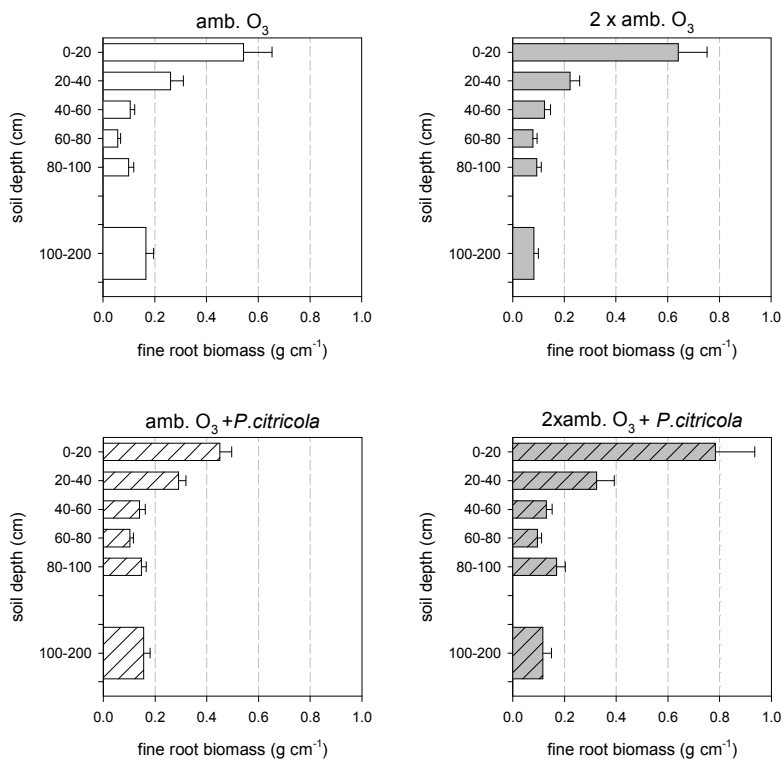


Figure 1. Vertical distribution of fine roots per tree and depth in the four treatments. Root biomass that was estimated for each depth was equally distributed to 1 cm. Given are means \pm 1SE, $n=8$. (Winkler *et al.* 2009).

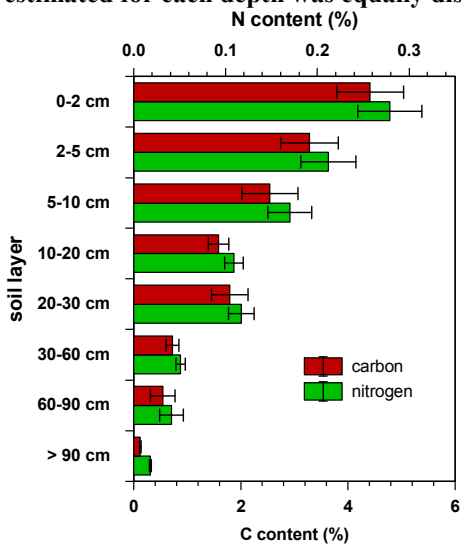


Figure 2. The dense sampling of the lysimeters ensured a detailed study of the reforming depth distribution of SOM properties (Mueller *et al.* 2009).

Example 3: After the investigation on the migration behavior of BTEX (Benzol, Toluol, Ethylbenzol and Xylol), MKW (oil hydrocarbons), PAK (polycyclic aromatic hydrocarbons) and Phenol, the soil in a lysimeter was retrieved to get information about the soil properties. To predict the seepage water in the region of selected contaminated areas of the ecological project “SOW BÖHLEN”, the lysimeter soil was retrieved to get the balance of the migration. The course of the BTEX concentration in the percolating water is given in figure 5.

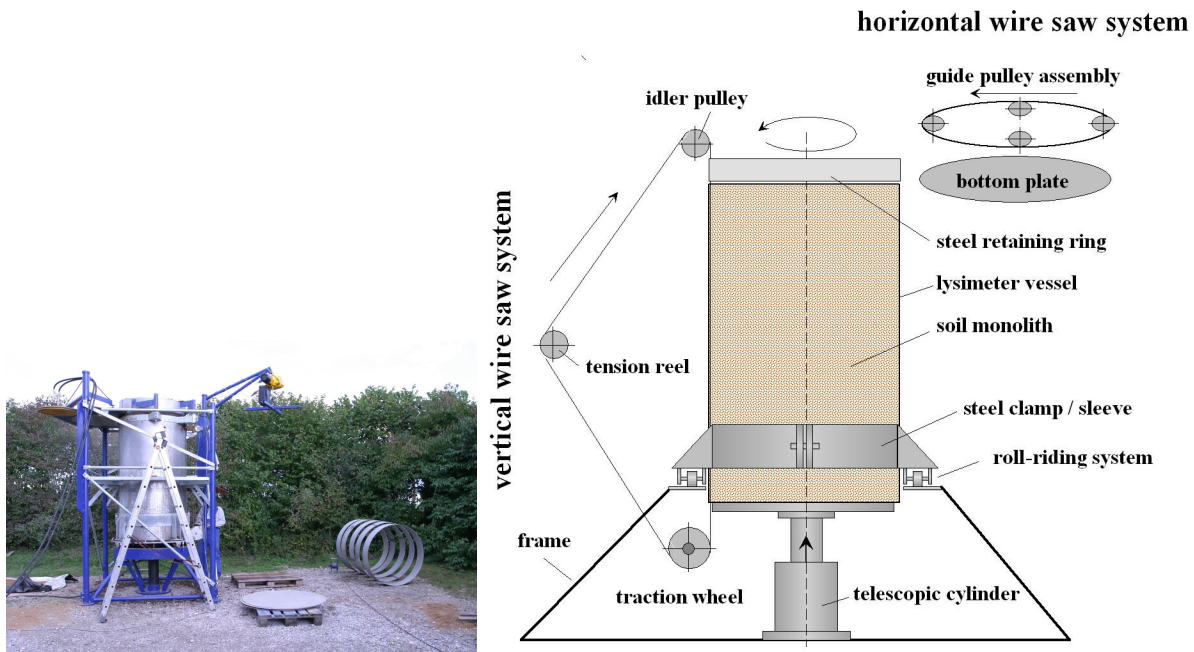


Figure 3. a) LSR in preparation for slicing a monolith, b) and the scheme of the apparatus.



Figure 4. Freshly cut soil slices (diameter 1.13 m, thickness 20 cm), 1) topsoil 0-20cm; 2) 20-40 cm; 3) 40-60cm; 4) 60-80 cm

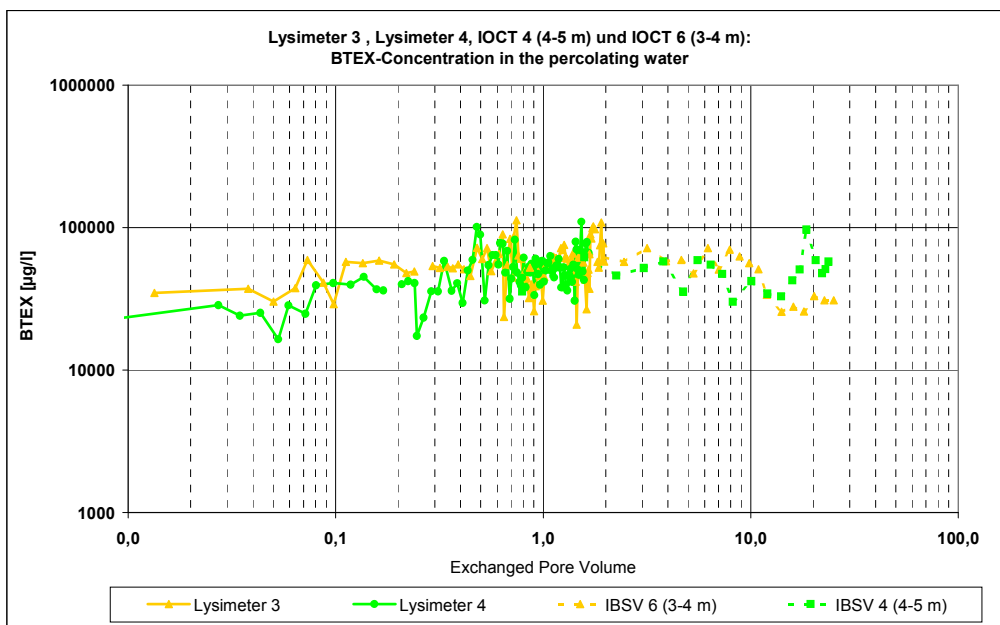


Figure 5. Lysimeter Tests in comparison with the results of IOCT in the laboratory scale EPV = cumulative soil water outflow/ pore volume.

Conclusions

This technique allows, for the first time, the analysis of the soil without disturbing a long-term experiment. Retrieving intact soil slices allows for a much broader range of applications of lysimeters. The main goal, was the retrieval of intact soil monoliths from the lysimeters, and the immediate dissection into slices, such

that the rhizosphere and its soil environment can be directly probed at several depths. The complete harvest at the end of the experiment by using the LSR technology enabled for the first time the assessment of fine and coarse root biomass of individual beech trees with a high vertical resolution down to two meter depth. The development of depth gradients of SOM composition and distribution within 4 years after soil disturbance and homogenization was studied in a lysimeter experiment with juvenile beech trees (*Fagus sylvatica* L.). By this approach it was possible to imitate the ploughing and concomitant planting of trees as it is common for newly established forests. The use of lysimeters with homogenised soil in eight replicates enabled an experiment unbiased by field scale heterogeneities. The sampling scheme applied to the given dense soil layers (0–2 cm, 2–5 cm, 5–10 cm and 10–20 cm) was crucial to study the subtle reformation of SOM properties with depth in the artificially filled lysimeters. Due to the combination of physical SOM fractionation with the application of ¹⁵N-labelled beech litter and ¹³C-CPMAS NMR spectroscopy a detailed view was obtained on vertical differentiation of SOM properties.

References

- Mueller C, Bruegemann N, Pritsch K, Stoelken G, Gayler S, Winkler JB, Kögel-Knabner I (2009) Initial differentiation of vertical soil organic matter distribution and composition under juvenile beech (*Fagus sylvatica* L.) trees. *Plant and Soil* DOI 10.1007/s11104-009-9932-1.
- Reth S, Seyfarth M, Gefke O, Friedrich H (2007) Lysimeter Soil Retriever (LSR) - a new technique for retrieving soil from lysimeters for analysis. *Journal of Plant Nutrition and Soil Science* **170**, 1-2.
- Reth S, Seyfarth M, Gefke O and Friedrich H (2006) Deutsche Patentanmeldung „Vorrichtung zur Entnahme eines Bodenmonolithen aus einem Lysimetergefäß“. Anmeldedatum 27.02.2006, Patentnr. 10 2006 010 158.
- Seyfarth M, Reth S (2008) Lysimeter Soil Retriever (LSR) – An application of a new technique for retrieving soils from lysimeters. (2008) *Water, Air, & Soil Pollution: Focus* **8**(2), 227-231.
- Winkler JB, Fleischmann F, Gayler S, Scherb H, Matyssek R, Grams TEE (2009) Do chronic aboveground O₃ exposure and belowground pathogen stress affect growth and belowground biomass partitioning of juvenile beech trees (*Fagus sylvatica* L.)? *Plant and Soil*, DOI 10.1007/s11104-009-9968-2.

Mobility of N, P, ethoprophos in three upland soils as affected by chemical fertilizer and composted manure under soybean-cultivated lysimeters

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Abstract

Lysimeter experiment (dia. 300 mm, soil length 350 mm) with soybean cultivation were conducted to investigate the effect of chemical fertilizer and compost on the mobility of N, P, and ethoprophos-a nematocide and an organophosphorus compound in three upland soils that were obtained from different agricultural sites of Korea: mesic Typic Dystrudepts (hill slope soil, Soil A); mixed, mesic Typic Udifluvents (floodplain soil, Soil B); artificially disturbed soils (soils under plastic-film house, Soil C).. Before treatments were implemented, soils were stabilized by repeated drying and wetting procedure for two weeks. Two types of treatments were applied to the lysimeters, application of urea at 60 kg N /ha plus KH_2PO_4 at 80 kg P_2O_5 /ha, and N-based application of composted manure considered to be 16.5% availability, with ethoprophos at 10 kg a.i. /ha. Soybean was grown for 46 days, and had 191 mm irrigation through seven occasions. The above-ground biomass and surface soil (0~15 cm) were sampled at 15, 21, 31, and 46 days after sowing. The soil solution was sampled at 25 cm depth, belonging to subsurface soil (16~35 cm). Inorganic N and P concentration in surface soil were highly correlated with N and P content of soybean leaf. Compost application enhanced P availability in Soils A and B, while chemical fertilizer facilitated N availability in all soils. Ethoprophos content of surface soil was not significantly different between treatments. Meanwhile, ethoprophos concentration in soil solution in Soil A was the highest, but was considerably reduced by composted manure. Therefore, the results suggested that composted manure could cause lower mobility than chemical fertilizer for ethoprophos.

Key Words

Lysimeter, compost, urea, nitrate, phosphate, ethoprophos, soybean.

Introduction

The impact of horticultural and agricultural uses of pesticides and nutrients on water quality generally starts as they leave the original point of application, i.e., through leaching or runoff, rather than the presence in soil (Pierzynski *et al.* 1994). Chemical fertilizer and composted manure generally cause the change in soil nutrient status and physico-chemical and biological properties, and thereby affect the migration potential of nutrients and pesticides from field. Less research, however, has been devoted to their effect on mobility of nutrients and pesticides. It is imperative that nutrient and pesticides are together considered to grasp the potential risk of non-point source on water quality in target soil. In this study, thus, lysimeter experiment, with soybean cultivation was conducted to investigate the effect of soil characteristics and inputs (chemical fertilizer, compost) on mobility of N, P, and ethoprophos.

Methods

Six plastic lysimeters of internal diameter 300mm and depth 400mm were packed with sea sand to 5mm from the bottom, and then with air-dried and sieved soils (< 2mm) described in table 1 to 450 mm from the top of sea sand. To ensure uniform packing, the lysimeters were packed in increments of 100 mm. Two treatments were set up. In treatment I upper 120mm soil was incorporated with urea (5 ¹⁵N atom%) 0.91g, KH_2PO_4 1.08 g, and 1.413g Mocap (a.i. 5%), equivalent to 10 kg a.i. ethoprophos /ha. In treatment II upper 120mm soil was incorporated with 100.95g composted manure, N-based application considering 16.5% N availability, and 1.413g Mocap (a.i. 5%). TDR was used to measure the soil's volumetric water content. Three-rod TDR probe (2 mm in diameter and 200 mm long) and soil solution samplers (2 mm diam. and 50 or 100 mm long) were installed horizontally into the lysimeters at the depth of 250 mm from soil surface. To determine water content of surface soil, three-rod probe was obliquely installed into lysimeters covered with from 50 mm to 150mm depth. Soil temperature sensors were installed at the depth of 100 and 250 mm from soil surface. TDR and soil temperature measurements were made daily between 15:00~18:00 at which nearly maximum soil temperature was maintained. Seven soybean (*Glycine max* Merr.) seeds were sowed in each

lysimeter. After germination, three seedlings were thinned and each four plant was sampled at 15, 21, 31, and 46 days after sowing, respectively. Sampled plants were analysed for dry biomass, N, and P content. At the same time, surface soil (0-15 cm) was sampled and analysed for N, P, and ethoprophos and the soil solution was sampled at the depth of 25 cm, belonging to subsurface soil (16-35 cm). In addition, at final sampling time, subsurface soil (16-35 cm) was sampled and analyzed for N, P, and ethoprophos followed by Sparks (1996) and Han et al. (2003). Tap water was surface-irrigated with a dripper to supply water.

Table 1. The physico-chemical properties of soils and composted manure used.

	Soil A	Soil B	Soil C	Compost
pH (1:1)	4.97	5.04	5.66	7.23a
Organic C (g/kg)	8.1	15	32.4	302.8
Total N (g/kg)	0.58	1.33	2.78	25.3
C/N ratio	14.1	11.3	11.6	12
Total P (g/kg)	0.24	0.51	3.86	18.79
C/P ratio	33.8	29.4	8.3	16.1
CEC (cmol/kg)	7.5	11.2	14.2	NAc
Mineral N				
NH ₄ ⁺ -N (mg/kg)	8.3	48.3	18.8	510.2 (2.0)b
NO ₃ ⁻ -N (mg/kg)	5	57.1	9.8	2372.0 (9.4)
Soil texture (g/kg)				
Sand	624.1	440	607.9	NA
Silt	270.9	413.2	292.7	NA
Clay	105	146.8	99.4	NA

^aThe ratio of soil:water was 1:5.; ^b% of total compost-N; ^cNot Applicable.

Results

During experiment, NH₄⁺-N contents in surface soil were a range of 0-18, 0-25 and 0-35 mg/kg and NO₃⁻-N contents were 2-27, 5-65, and 0-45 mg/kg in Soils A, B, and C, respectively. Soils A and C had maximum mineral-N content in surface soil on day 21 but a Soil B by day 32. Mineral-N content in surface soil was generally much higher in T I than in T II, whereas soluble NO₃⁻-N content in subsurface soil had slightly lower in T I than that in T II at initial time after treatments.

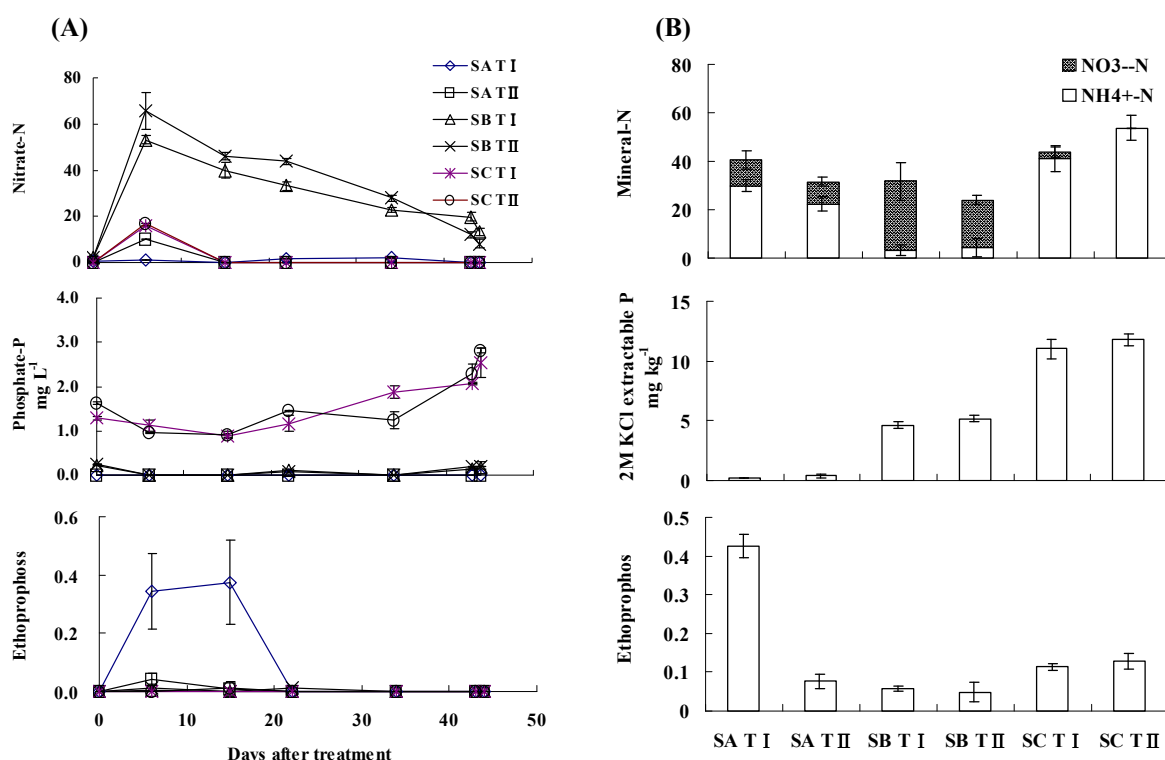


Figure 1. (A) Soluble nitrate-N, phosphate-P, and ethoprophos content per soil volume in subsurface soil, (B) Mineral-N, 2M KCl extractable P, and ethoprophos content in subsurface soil at final sampling. SA, SB, and SC indicate Soils A, B, and C, respectively; T I and T II indicate chemical fertilizer and compost treatment, respectively. Values are the means of triplications. Vertical bars indicate standard deviations of the means.

The nitrate concentration in soil solution of subsurface soil decreased with soybean growth, whereas phosphate concentration did not. This suggested that the P concentration in the soil solution did not readily decrease due to continuous P supply from a P accumulated matrix. More careful P management, therefore, was essentially required because P loss could hardly be controlled in P accumulated soil. The initial concentration of ethoprophos when incorporated with soil was 5.76 ± 0.87 mg soil/kg. During experiment, the ranges of ethoprophos content in surface soil was 0.05-0.11, 0.16-2.7, and 0.27-1.66 mg/kg for Soils A, B, and C, respectively. Soil A had an abrupt decrease in ethoprophos content by day 14th and then was almost constant. Unlike Soil A, Soils B and C had a decreasing pattern with time in ethoprophos content. Contrasted with the surface soil, soluble ethoprophos content in the subsurface soil was much higher in Soil A than those in the other soils, especially soils with chemical fertilizer treatment.

Conclusion

This study suggested that vertical movement of nitrate, phosphate, and ethoprophos was relatively high in Soil B, Soil C, and Soil A, respectively, depending on water transport and sorption characteristics. In addition, it was concluded that composted manure resulted in lower mobility for ethoprophos than chemical fertilizer

References

- Guo L, Jury WA, Wagenet RJ, Flury M (2000) Dependence of pesticide degradation on sorption: nonequilibrium model and application to soil reactors. *Journal of Contaminant Hydrology* **43**, 45-62
- Han KH, Kim CS, Ro HM, Lee SM, Yoo SH (2003) Degradation of ethoprophos in three physicochemically different soils treated with composted manure and chemical fertilizer. *Bulletin of Environmental Contamination and Toxicology* **70**, 520-526.
- Han KH, Choi WJ, Han GH, Yun SI, Yoo SH, Ro HM (2004) Urea-N transformation and compost-N mineralization in three different soils as affected by the interaction between both N inputs. *Biology and Fertility of Soils* **39**, 193-199.
- Han KH., Ro HM., Cho HJ, Kim LY, Hwang SW, Cho HR, Song KC (2008) Mobility of nitrate and phosphate through small lysimeter with three physico-chemically different soils. *Korean Journal of Soil Science and Fertilizer* **41**, 260-266
- Leinweber P, Meissener R (1999) Management effects on forms of phosphorus in soil and leaching losses. *European Journal of Soil Science* **50**, 413-424
- Pierzynski GM, Sims JT, Vance GF (1994) 'Soils and Environmental Quality'. (Lewis Publishers).
- Sparks DL (eds) (1996) 'Methods of Soil Analysis, Part 3. Chemical methods, 3rd edn'. (ASA and SSSA: Madison, WI).

Optimizing the experimental design of unsaturated soil columns

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Abstract

The apparent simplicity of constructing soil columns conceals a number of technical issues which can seriously affect the outcome of an experiment. This review examines the literature to provide an analysis of the state of the art for constructing both saturated and unsaturated soil columns. Common design challenges are discussed and best practices for potential solutions are presented. This review will assist soil scientists, and other environmental professionals in optimizing the construction and operation of soil column set-ups in order to achieve their experimental objectives while avoiding serious design flaws which can compromise the integrity of their results.

Key Words

Lysimeters, construction, best practices

Introduction

Soil columns have been used for over a century in the study of hydrogeological properties (Darcy, 1856). More recently, soil columns and lysimeters have been used to evaluate transport models, to monitor the fate and mobility of contaminants in soil and for evapotranspiration studies. For the purposes of this review, a soil column is characterized as a discrete block of soil located either outdoors or in a laboratory, which allows control or measurement of the infiltration and which incorporates equipment for the total recovery of the effluent. This is usually achieved by encasing the soil column in a rigid and impermeable shell material, both for structural reasons and to prevent fluid loss.

There is considerable variation in the soil columns which have been reported in the literature. Some of the smallest measure 1 cm diameter and 1.4 cm in length (Voegelin *et al.* 2003) while some of the largest measure 2 m x 2 m x 5 m (Mali *et al.* 2002). Despite the ubiquitous use of soil columns no attempt has ever been made to outline the best practices for constructing these useful pieces of equipment. The apparent simplicity in constructing lysimeters conceals several critical design issues which could seriously compromise subsequent experimental results. The purpose of this article is to review and summarize the literature and provide practical guidance concerning the state of the art in their construction.

Repacked soil columns

Although the repacking of laboratory columns has received relatively little attention in the literature, Bromly *et al.* (2007) have shown that it will significantly influence the resulting solute transport behaviour of the columns. The goal of repacking is to restore the bulk density of the soil to a value similar to that observed naturally, while avoiding the formation of preferential flow pathways. Several repacking methods have been reported in the literature. The most common approach is dry or damp packing.

Dry or damp packing involves loading small discrete amounts or “lifts” of dry or damp soil into the column and then mechanically packing it either by hand or with some type of ram or pestle. Oliviera *et al.* (1996) demonstrated that in order to produce homogeneous sand packing, dry deposition must be in increments of 0.2 cm followed by compaction with a metal pestle. However, the literature shows few studies in which dry deposition is done in lifts smaller than 1 cm and some in which the lifts were as much as 15 cm (Plummer 2004). Several studies which employed dry or damp packing also noted the importance of lightly scarifying the soil surface after compaction and before addition of another lift in order to ensure hydraulic connectivity between the layers (Plummer 2004).

Another common approach is slurry packing (Sentenac 2001). Slurry packing involves saturating the soil with an excess of water, then letting it settle at the bottom of the column. Saturation is achieved either by stirring the soil into the water prior to pouring it into the column as a slurry, or by filling the column with water and then slowly pouring or sprinkling dry soil into the column while stirring. Oliviera *et al.* (1996) found that the best wet packing technique involved depositing thin layers of saturated sand into water while vibrating the column. They observed that this technique produced the highest density uniform packing without causing any lateral particle size segregation.

Lysimeter design issues

The most critical design issue with homogeneous, unsaturated soil columns is to avoid unnatural preferential flow paths. While natural preferential flow paths are expected or even desirable in monoliths, they may also be formed unintentionally in the construction of unsaturated soil columns, and these must be avoided. These flow paths will cause spatial heterogeneity in the transport of solutes through a porous medium and will therefore significantly bias any experimental results. Sidewall flow refers to a preferential flow of fluid in proximity to the rigid outer wall of a soil column (Sentenac *et al.* 2001; Corwin 2000). In repacked soil columns, other undesirable forms of preferential flow include macropore flow or fingering (Wilson *et al.* 1995).

Sidewall flow may be caused by improper packing of the column or flexing of the column walls during or after the soil has been repacked. However, there is evidence that preferential sidewall flow occurs even when no space or gap exists due to an increase in the permeability of the soil in contact with the sidewall (Schoen *et al.* 1999). Sentenac *et al.* (2001) observed that the flow velocity at a column wall can be between 1.11 and 1.45 times the flow velocity in the column center. They also observed that sidewall flow increased with larger soil particle sizes and that it is more exaggerated at small hydraulic gradients.

Various strategies have been proposed in the literature to overcome sidewall flow including roughening the sidewall (Smajstrla 1985), gluing sand to it (Sentenac *et al.* 2001) or by installing annular rings on the interior surface of the column prior to the addition of soil (Corwin 2000). Another (unpublished) approach advocated by the United States Department of Agriculture recommends wetting the inside of the column then packing it with a swelling clay such as montmorillonite. The excess (dry) clay is allowed to fall out of the column while the hydrated clay forms a liner on the column wall. The soil to be investigated is then carefully packed into the column without disturbing the clay layer.

Macropore flow refers to any flow which takes place outside of the normal pore structure of the soil, such as in wormholes or decayed roots. While these may play a more significant role in monolith-type soil columns, macropores still exist in apparently homogeneous repacked soil columns on account of the heterogeneity of the soil grains themselves (Cortis and Berkowitz 2004).

Fingering occurs when instability develops in the wetting front as it moves through coarse unsaturated soils such as sands (Selker *et al.* 1999). Parlange *et al.* (1990) showed that the size of the finger width were a function of the soil grain size, with silts having fingers on the order of 1 m in diameter and coarse sands having fingers on the order of 1 cm. While fingering has generally only been observed in practice in soils that are predominantly sand, water-repellency of the soil has also been implicated (Bauters *et al.* 1998). Selker *et al.* (1999) suggest that finger width is not strongly influenced by the flux through the system so long as the rate of infiltration is well below the saturated conductivity. When the flux is increased up to the rate of the saturated hydraulic conductivity of the soil, fingers will grow in width and frequency until they finally merge into a single wetted front without fingers. Since it has been demonstrated that once a finger is formed in a particular location it will persist until the soil has either been dried or saturated completely (Glass *et al.* 1989), they can strongly influence the results of an experiment. Fingering is most likely to occur when the soil being infiltrated is initially extremely dry (Lui *et al.* 1993).

One other significant issue in unsaturated columns is obtaining the effluent in such a way that the column remains unsaturated. The pressure potential in unsaturated soil is always negative due to capillary and other forces, becomes zero at the water table and increases below the water table due to the pressure from the overlying water (Wierenga 1995). This means that suction must be applied to unsaturated soil in order to extract the pore water. However, attempting to sample pore water by applying suction to an open ended pipe attached to the base of a soil column will fail because only air will be drawn in (Wilson *et al.* 1995). For this reason, a porous material is used as an interface to ensure that pore liquids in the soil are in hydraulic contact with liquid within the sampling device (Plummer *et al.* 2004).

Porous materials which have been used experimentally include ceramic, porous PTFE, fritted glass, porous stainless steel, porous plastic and fibreglass wicks. Two key considerations in the choice of a porous material is the bubbling pressure of the material (Everett and McMillion 1985) and whether or not the material is chemically compatible with the solute under consideration.

The bubbling pressure is the maximum suction that can be applied to soil water by a porous plate before air will begin to enter the plate instead of pore water. In most applications, the vacuum applied to the porous material need not be very high. The maximum theoretical suction that can be applied to the soil is 1 bar. However, the hydraulic conductivity of a soil at 1 bar matric potential is so low that any column experiment would take a prohibitively long time (Wilson *et al.* 1995). As a result, most unsaturated soil column studies are conducted at or near the field capacity of the soil. In coarse textured soils, this means that the soil matric potential will be between 0.04 to 0.06 bars and from 0.06 to 0.1 bars in fine textured soils (Wierenga 1995).

These pressures can be easily achieved without pumps by using a hanging column of water. It should also be noted that even under these favourable conditions, PTFE porous materials may not be able to achieve a sufficiently high operational suction to bring the water content of a soil down to field capacity. In finer textured soils such as silts and clays, the operational suction of porous PTFE is unlikely to successfully withdraw pore water. How much suction should be applied is still under some debate, but a consensus is emerging that the methodology to obtain the most representative soil water samples is to apply a suction equivalent to the ambient matric potential which exists at the same depth in the soil (Kosugi and Katsuyama 2004). However, higher-than-ambient suctions will allow a faster collection of leachate. While this will create an artificial flow field within the column, this may be an acceptable tradeoff depending on the experimental objectives, particularly in soils which have very low permeabilities. In general, the suction applied will be dependent on the soil type, the amount of water required for analysis, the soil water content and the time of the applied suction.

One serious problem with the use of porous materials in soil column experiments is pore clogging, and Everett and McMillan (1985) recommend the use of a silica flour pack between the porous material and the soil to be tested to prevent colloids in the soil from reaching and plugging the porous surface. They found that the use of a silica flour pack was essential when using PTFE porous materials. Clogging of porous surfaces in lysimeters may also be caused by biofilms.

Another experimental approach which is encountered frequently in the literature is to allow the free drainage of soil pore water from the base of the soil column without any applied suction (Derby *et al.* 2002).

Frequently, the soil column will be installed on a layer of gravel or on a metal screen. In these experimental setups, the soil matric potential must increase to 1 bar before drainage begins, which means by definition that a saturated zone must form at the base of the soil column before flow can occur. This experimental approach is particularly common in large and very large unsaturated soil columns (Mali *et al.* 2002). However, Derby *et al.* (2002) point out that gravity drainage may cause an unrealistic moisture regime, and Flury *et al.* (1999) showed with numerical simulations that the saturated seepage face conditions influence both the water flow and solute concentration in the sampled leachate.

One final issue affecting the operation of unsaturated soil columns concerns unsaturated dispersion. At the microscopic scale, water moves through pores of a homogeneous porous material with some velocity that varies according to the geometry of the individual pore spaces. However, the macroscopic water velocity measured in the lab represents an average movement of water through a representative volume (Fogg *et al.* 1995). The deviations of fluid velocity in the individual pore spaces from the overall average produces spreading and dilution, which is called dispersion. This behaviour is modelled by assuming that it is analogous to Fick's law of diffusion (Bear 1972). However, Fick's law can only be valid when a fluid or solute has passed through enough micro scale heterogeneities that the overall behaviour becomes representative of the volume as a whole (Selker 1999). In a homogeneous saturated soil, this distance is on the order of several thousand soil grains (Yeh 1998) and therefore it is rarely an issue experimentally. However, because there are fewer flow pathways in unsaturated conditions, a solute must pass through a much larger representative volume before its behaviour becomes representative of the soil column as a whole. Often, this distance is longer than the experimental soil column itself (Yeh 1998). As a result, the concentration of solutes which are detected in the effluent is characterized by an early breakthrough and multiple peaks. This is even truer in situations where the heterogeneities are not micro-scale, but are macro-scale themselves, as is explicitly the case with monoliths.

Conclusions

While construction of a lysimeter for theoretical or applied studies appears to be straightforward, there exist a number of technical issues which could seriously bias results. This review article provided insight into the state of the art for the construction and manufacture of these useful experimental tools in order to provide researchers with the best practices available to construct soil columns which will meet their experimental needs.

References

- Bauters TWJ, DiCarlo DA, Steenhuis TS, Parlange JY (1998) Preferential flow in water-repellent sands. *Soil Science Society of America Journal* **62**(5), 1185-1190.
- Bear J (1972) 'Dynamics of fluids in porous media.' (American Elsevier Pub. Co.: New York,) xvii, 764 p.
- Bromly M, Hinz C, Aylmore LAG (2007) Relation of dispersivity to properties of homogeneous saturated repacked soil columns. *European Journal of Soil Science* **58**(1), 293-301.

- Cortis A, Berkowitz B (2004) Anomalous transport in "classical" soil and sand columns. *Soil Science Society of America Journal* **68**(5), 1539-1548.
- Corwin DL (2000) Evaluation of a simple lysimeter-design modification to minimize sidewall flow. *Journal of Contaminant Hydrology* **42**(1), 35-49.
- Darcy H 'Les fontaines publiques de la ville de Dijon: Exposition et application des principes a suivre et des formules a employer dans les questions de distribution d'eau.' ([s.n.]: [S.l.]) microfilm.
- Derby NE, Knighton RE, Montgomery BR (2002) Construction and performance of large soil core lysimeters. *Soil Science Society of America Journal* **66**(5), 1446-1453.
- Everett L, McMillion L (1985) Operational ranges for suction lysimeters. *Ground water monitoring review* **51**(5), 51-60.
- Fogg G, Nielsen D, Shibberu D (1995) Modeling Contaminant Transport in the Vadose Zone: Perspective on State of the Art. In 'Handbook of vadose zone characterization and monitoring'. (Eds. Wilson L, Everett L, Cullen S), pp. 249-266. (Lewis Publishers: Boca Raton).
- Glass R, Steenhuis T, Parlange, J-Y (1989) Mechanism for finger persistence in homogeneous, unsaturated, porous media: theory and verification. *Soil Science* **148**(1), 60-70.
- Kosugi K, Katsuyama M (2004) Controlled-suction period lysimeter for measuring vertical water flux and convective chemical fluxes. *Soil Science Society of America Journal* **68**(2), 371-382.
- Liu CM, Zhang XY, Zhang YQ (2002) Determination of daily evaporation and evapotranspiration of winter wheat and maize by large-scale weighing lysimeter and micro-lysimeter. *Agricultural and Forest Meteorology* **111**(2), 109-120.
- Mali N, Urbanc J, Leis A (2007) Tracing of water movement through the unsaturated zone of a coarse gravel aquifer by means of dye and deuterated water. *Environmental Geology* **51**(8), 1401-1412. [In English]
- Oliveira IB, Demond AH, Salehzadeh A (1996) Packing of sands for the production of homogeneous porous media. *Soil Science Society of America Journal* **60**(1), 49-53.
- Plummer MA, Hull LC, Fox DT (2004) Transport of carbon-14 in a large unsaturated soil column. *Vadose Zone Journal* **3**(1), 109-121.
- Schoen R, Gaudet JP, Elrick DE (1999) Modelling of solute transport in a large undisturbed lysimeter, during steady-state water flux. *Journal of Hydrology* **215**(1-4), 82-93.
- Selker JS, Keller CK, McCord JT (1999) Vadose zone processes. (Lewis: Boca Raton, FL)
- Sentenac P, Lynch R, Bolton M (2001) Measurement of the side-wall boundary effect in soil columns using fibre-optics sensing. *International Journal of Physical Modelling in Geotechnics* **4**, 35-41.
- Smajstrla A (1985) A field lysimeter system for crop water use and water stress studies in humid regions. *Soil & Crop Science Society of Florida - Proceedings* **28**.
- Wierenga P (1995) Water and Solute Transport and Storage. In 'Handbook of vadose zone characterization and monitoring'. (Eds. Wilson L, Everett L, Cullen S). (Lewis Publishers, Boca Raton).
- Wilson LG, Everett LG, Cullen SJ (1995) Handbook of vadose zone characterization and monitoring. (Lewis, Boca Raton, Fla.) xii,730p.
- Yeh T (1998) Scale issues of heterogeneity in vadose-zone hydrology and practical solutions. In 'Scale Dependence and Scale Invariance in Hydrology' (Ed. Sposito G), pp. 224-265. (Cambridge University Press, Cambridge).

Physical Straining of *Cryptosporidium parvum* Oocysts through Saturated Soils

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Abstract

The colloid-sized *C. parvum* oocysts may be physically strained through porous media during transport. However, most of studies on *C. parvum* oocysts were performed with a constant flux (CF) controlled by a peristaltic pump, in which the unsteady flux caused by the physical straining mechanism was ignored. In this study, we first compared two systems in which oocysts transport through homogenous pure sand or soils either by a CF or by a constant pressure head (CP). The results showed oocysts solution flux (J_o) reduced remarkably in a CP system, but not in a CF system. More oocysts from the effluents in CF system were observed than in CP system, indicating that oocysts breakthrough was overestimated in CF system. Using the CP system, 6 intact soils typical of Ireland were further investigated. One soil had oocyst breakthrough earlier than Br^- , and J_o was nearly identical to Br^- flux (J_B) due to macropore flow. For the other five soils oocyst breakthrough was later than Br^- , and J_o tended to decrease with pore volume. The decrease of J_B was not found during the experiments. The unsteady-state flux of oocysts solution put forward a new challenge for us how to simulate the colloid-sized pathogen transport in soils.

Key Words

Breakthrough curve, *Cryptosporidium*, Physical straining, Transport

Introduction

Cryptosporidium parvum is a zoonotic protozoan parasite that can infect the intestines of animals as well as humans (Fayer 2008). It poses a significant risk to public health through incidences of human cryptosporidiosis, and has become a global concern to water resource managers since the 1993 outbreak in Milwaukee, US. The main source of *C. parvum* oocysts is from infectious calves when agricultural water including runoff, infiltration and subsurface flow from dairies, calving house, silage and grazing lands may be loaded with high concentrations of oocysts. There is little knowledge of the transport of *Cryptosporidium* oocysts in agricultural ecosystems (Fayer 2004; Pachepsky *et al.* 2006).

Some studies have examined the transport and retention behavior of *Cryptosporidium* oocysts in repacked sand columns under a steady-state flux controlled by a peristaltic pump (Brush *et al.* 1999; Harter *et al.* 2000; Logan *et al.* 2001; Bradford and Bettahar 2005). They are more interested in how oocysts are filtered through the homogeneous porous media either by the particle size or solution chemical properties (Bettahar 2005, Brush *et al.* 1999; Harter *et al.* 2000; Logan *et al.* 2001). Harter *et al.* (2000), and Logan *et al.* (2001) emphasized that decreasing the median sand size tended to produce lower effluent concentrations and greater oocyst retention near the column inlet. Bradford and Bettahar (2005) further postulated that three physical mechanisms of attachment, detachment and irreversible straining might be involved in the tailing and heterogeneous distribution of oocysts at depth. However, we hypothesize at the steady-state flux the colloid-sized oocysts may be forced to pass through the pores. The filtered oocysts will be as a result overestimated. On the other hand, the homogeneous porous media is not able to represent effects of structured soil on oocyst breakthrough behavior.

In Ireland *C. parvum* is a potentially significant zoonotic disease due to the large bovine population (~6 million cattle in 2008) and the dependence on surface water or shallow groundwater for drinking water supply. Agricultural soils are typically glacially derived and mostly classified by association as Podzols, Cambisols, Luvisols and Gleysols from FAO world reference base for soil resources. There is a wide range of texture, structure and other properties, the influence of which cannot be properly established using disturbed soil, therefore the objectives of this research were: (i) to prove the physical straining of oocysts through porous media; and (ii) to investigate the role of undisturbed soil structure in oocysts transport and retention.

Materials and Methods

Undisturbed soil cores and pure sand columns

Nine typical grassland undisturbed soil cores (20 cm high, 10 cm diameter) from Ireland with a limited range of soil texture and wider range of soil organic C were used (Table 1). A composite disturbed sample from five points around the same fields was taken, air-dried and ground to <2 mm for determining soil properties. Two pure sand sizes and one seized <2 mm CG soil were prepared homogeneous porous media. The three homogeneous columns were used to compare oocysts breakthrough between constant flux (CF) and constant pressure head (CP) systems. In CF system the flux was determined by the flux of Br⁻ solution in CP system.

Table 1. Some selective soil properties of nine soils present in permanent pastures in Ireland

Soil code	Silt	Clay	SOC [†]	CEC [†]	Total pore	Macropore [†]	K _s [†]	pH
	g/kg			mmol/kg	cm ³ cm ⁻³		cm/day	[-]
S02	397	159	27.1	169	0.477	0.109	2.94×10 ³	6.08
S01	440	187	40.8	202	0.571	0.060	7.00×10 ²	5.72
CG	431	212	44.0	187	0.533	0.096	4.42×10 ²	5.32
EG	424	221	48.4	212	0.596	0.039	9.26×10 ¹	6.57
OG	364	162	30.0	151	0.525	0.036	7.30×10 ¹	5.6
JSG	217	116	16.3	92	0.419	0.008	2.16×10 ¹	6.33
KG	513	102	90.5	259	ND	ND	<1.0×10 ⁰	6.3
RG	444	162	37.5	163	ND	ND	<1.0×10 ⁰	6.56
CCG	496	217	72.3	225	ND	ND	<1.0×10 ⁰	5.29

[†]SOC, soil organic carbon, CEC, Cation exchange capacity, Macropore, >60 μm diameter, K_s, saturated hydraulic conductivity of distilled water; ND, not determined.

Cryptosporidium parvum oocysts were purchased from Creative Science Company, UK. These oocysts were purified from manure of experimentally infected calves by sucrose and Percoll gradient centrifugation and water washes. They were stored in 0.1% PSB (phosphate buffered saline) solution at 4 °C before use. The number of oocysts in the stock solution was about 5.0 × 10⁸ oocysts/ml. The oocyst staining protocol was used after following the instruction of the Dynabeads[®] anti-*Cryptosporidium* kit (Invitrogen, Norway).

Column Experiment

The columns were firstly saturated from the bottom with distilled water for an overnight. Then about 1-2 pore volume of 0.1 M NaBr solution was run through the column from top to bottom, followed by another 1-2 pore volume of 2.0×10³ oocysts/ml solution. The oocysts reservoir was placed on a stirrer to keep the oocyst homogeneously mixed during the experiment. The breakthrough of Br⁻ and oocysts solutions was pushed through the column under a 22 cm CP between the inlet and the outlet or under a CF controlled by a peristaltic pump. The homogenous pure sand and disturbed soil were performed in the both systems, while the undisturbed soils were only performed in CF system. The effluent was collected from the outlet periodically and the time (Δt) and volume (ΔV) were recorded. The flux of distilled water (J_w), Br⁻ solution (J_B) or oocyst solution (J_o) was calculated by the following equation.

$$J_i = \frac{\Delta V}{A \Delta t} \quad (1)$$

where A is the cross area of the soil column (78.5 cm²), and i is the flow phase of distilled water, Br⁻ solution or oocysts solution.

Results and Discussion

Comparison of CF and CP systems

Figure 1 presents the relative concentration (C_i/C₀) of Br⁻ and oocyst in the effluents as a function of pore volume. For the coarse sand column, the colloid-sized oocysts breakthrough curve is nearly identical to the ionic Br⁻ curve either in CF system or in CP system. That means the physical straining is negligible in the coarse sand. For the fine sand column, the breakthrough curve of oocysts is consistent with the Br⁻ in CF system, whereas the filtration of oocysts was lower than the Br⁻ in CP system. For the disturbed soil, only few oocysts passed through columns in CF system, and even less in CP system. The flux of oocysts was at

steady-state, identical to Br^- in the coarse and fine sand columns (Figure 2). However, in the disturbed soil column, the flux of oocysts was decreased in the entire period due to the blockage of pores by oocysts. This physical function may be caused mainly by the oocysts preferentially attached to soil particles rather than oocysts themselves. These results clearly prove that the physical straining of colloid-sized oocysts through porous media may be readily ignored in CF system.

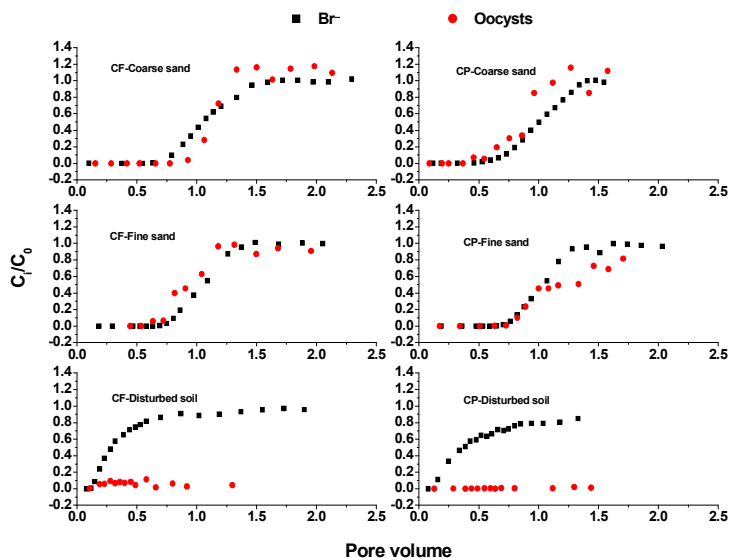


Figure 1. Breakthrough curves of Br^- and oocysts in homogenous columns.

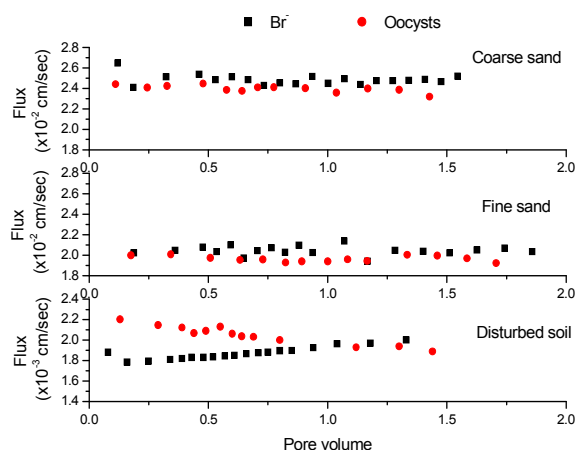


Figure 2. Flux of Br^- and oocysts through homogeneous columns in CP system.

Structured soils

The Br^- and *Cryptosporidium* oocyst effluent concentration curves and the related J_B and J_0 values of the six soils used for the soil column experiments show the relative effluent concentrations (C_i/C_0) as a function of pore volumes (Figure 3). Br^- concentration increased with pore volume up to the initial concentration. The oocyst breakthrough curve was different to the Br^- curve. The oocyst concentration increased at the beginning of the experiment and then decreased to some extent with the exception of EG, in which oocyst concentration always increased but remained at very low concentrations during the first pore volume. For the S02 soil the oocyst breakthrough curve was earlier than Br^- , while J_0 was nearly identical to J_B during the whole experiment. In the other five soils, the oocyst breakthrough curves were all later than Br^- and their J_0 tended to decrease with pore volume. The change in J_B was minimal. The time to start of decrease in J_0 tended to coincide with the decrease of oocyst concentration. The reduction of J_0 indicated that the CP system could keep ionic Br^- under steady state flow but failed for colloid-sized oocysts. As a result, the oocyst concentration of the effluent eventually decreased when the oocyst flow was reduced. The decrease in oocyst flow probably means that physical straining and trapping of oocysts in the soil pores was occurring.

The decrease in oocyst concentration with an increase of pore size indicated that oocysts were physically strained or trapped in smaller pores. With the blockage of pores by oocysts, the flux of oocysts decreased as shown in Figure 3. The pores smaller than the oocysts could not transfer oocysts with a fixed pressure head

(22 cm in this case), but if using a peristaltic pump some oocysts might be forced to pass through colloid-sized pores as discussed previously. The results suggest that the boundary of mobile and immobile pores sometimes used in soil hydrology, or even in colloid-sized *Cryptosporidium* transport, depends on whether the experiment conducted uses a constant head (giving the potential for a change in effective pore size which cannot be readily modelled using classical theory) or a constant flux that might 'force' oocysts through pores that would not normally conduct them. Oocyst removal by six structured soils was calculated to range from 0.076 up to 0.864 and it was more closely related to macroporosity than to total porosity. The oocyst fraction either in the effluent or in the pores was significantly related with macroporosity and hydraulic conductivity ($P < 0.05$), which plays a negative role in the removal fraction.

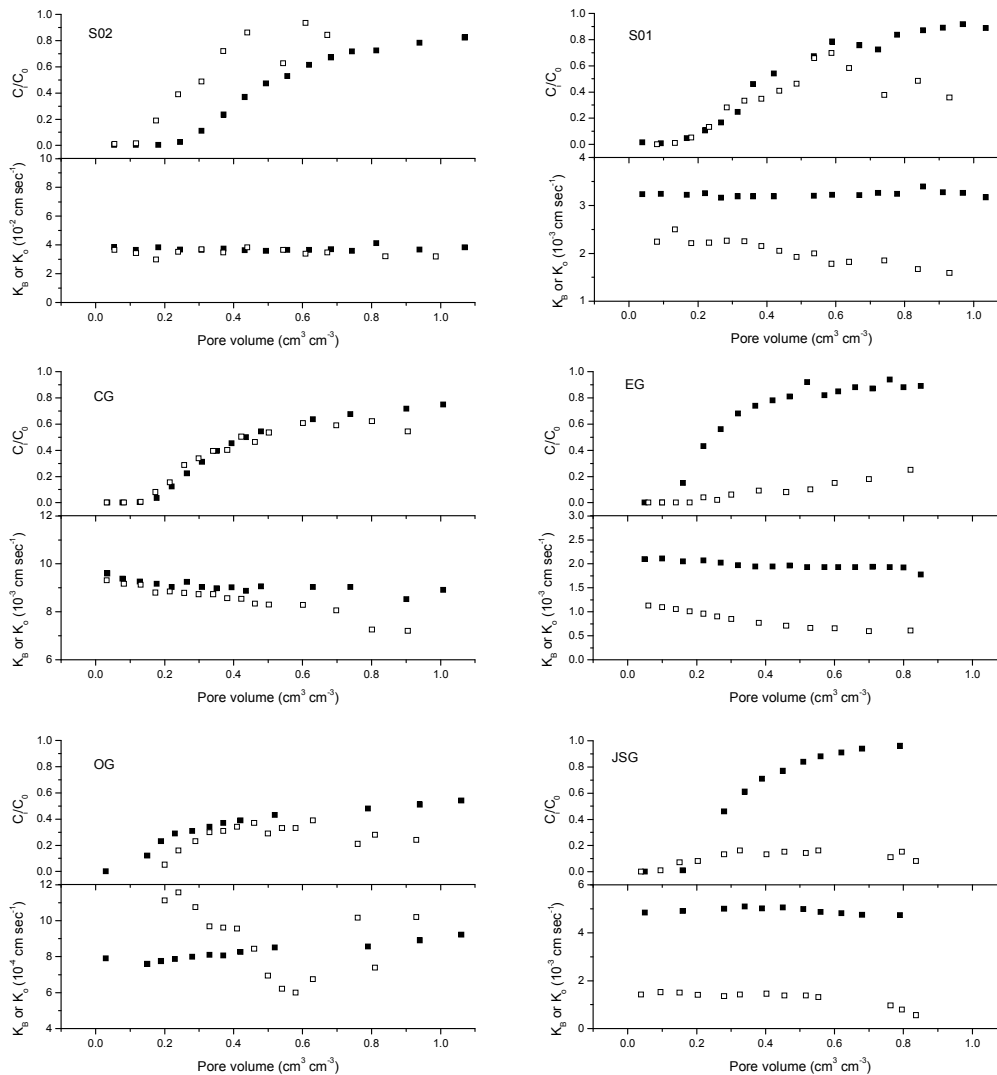


Figure 3. Breakthrough curves and saturated hydraulic conductivity of Br^- (solid squares) and oocysts (open squares) in structured soil cores.

Conclusions

For colloid-sized *Cryptosporidium parvum* oocysts transport through soils or porous media, the filtration of oocysts could be overestimated in the steady-state flux system. Use of a constant pressure head system the flux of oocysts solution decreased and the reduction of its concentration coincided in the effluent as a result of physical straining. These results provide an additional evidence to demonstrate that straining is one of important physical mechanisms regulating colloid-sized oocyst transport through structured soils.

Major References

- Bradford SA, Bettahar M (2005) Straining, attachment, and detachment of *Cryptosporidium* oocysts in saturated porous media. *Journal of Environment Quality* **34**, 469-478.
- Bradford SA, Scott R, Bettahar M, Šimůnek J (2002) Physical factors affecting the transport and fate of colloids in saturated porous media. *Water Resource Research* **38**, 1327, doi:10.1029/2002WR001340.

Recultivation of a potassium mining waste dump with municipal sewage sludge compost

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Abstract

The mining company, Glückauf Sondershausen Entwicklungs- und Sicherungsgesellschaft mbH (Germany), has its origin in the potassium and salt industry. The mining dumps have a high salt content and contain a high potential for the contamination of soil and water resources. An effective measure to protect the environment is to cover the dumps with suitable minerals to prevent saline water penetrating into the near-surface water. In our study, we set up a recultivation layer by mixing municipal sewage sludge compost (SSC) with a sandy soil to investigate the influence of this material on the quantity and quality of seepage water and to analyze the growth of bioenergy crops. These crops can be used for biogas generation. Sewage sludge composts have a high water storage capacity and contain a huge amount of plant available nutrients.

Key Words

Recultivation layer, energy crops, infiltration, evapotranspiration.

Introduction

Mining activities, especially lignite and potassium mining have along tradition in central parts of Germany. As a result of these mining activities a lot of dumps and tailings are located in the region and they are dangerous for the environment (Knappe *et al.* 2004). An environmental friendly and simple solution to protect these dumps is the covering of the surface as well as the slopes with suitable materials to obtain a vegetation layer to minimize the leachate and to use the established soil layer for the production of biomass. A suitable material can be municipal sewage sludge compost (SSC) with its formidable chemical and physical characteristics, like a high content of organic matter and a high water storage capacity (Gomiscek 1999, Bernsdorf *et al.* 2008).

The potassium dump near the town Sondershausen (Thuringia, Germany) has a surface area of 65 ha. To avoid the impact of high water soluble salt penetration into the ground and into the surface water, three layers must to be set up (Kali-Halden-Richtlinie 1999). This study is focused on the establishment of the top layer - the so-called “recultivation layer”. Different mixing ratios between SSC and sandy soils are shown and discussed regarding the decreasing of the leaching capacity of essential nutrients.

Methods

The experimental plot with an area of 3600 m² was set up in July 2007 on a plateau site of the potassium dump near the mentioned town Sondershausen. With the trial the following parameters have been tested:

- two different types of the thickness of the recultivation layer (70 and 100 cm) and
- three mixture ratios between the SCC and a sandy soil (SSC added at 0, 50 and 75% by volume).

Every year the following three crop rotations were cultivated: *Zea mays*, *Triticum aestivum*, *Dactylis glomerata*, *Sorghum sudanense* and *Brassica napus*.

To control the water and solute balance of the SSC-variants, 48 simple (non-weighable) gravitation lysimeters, with a diameter of 40 cm and a depth of 70 and 100 cm, were installed (the vessels were filled with mentioned substrates) and the leachate was collected once per month as a mixed sample and analyzed in both quantitatively and qualitatively. The chemical analysis was focused on parameters, which are essential for the plant growth, especially nitrate-nitrogen (NO₃-N), ammonium-nitrogen (NH₄-N), ortho-phosphate (PO₄-P), pH-value and electrical conductivity. Furthermore, 50 simple lysimeters (seepage water sampler), with a diameter of 20 cm and a depth of 100 cm, were set up as an additional outdoor trial under quasi laboratory conditions to get detailed information about seepage water quantity and quality by different mixing ratios of SSC with a sandy soil and cropping of different plants.

The chemical characteristics of SSC, nutrients as well as pollutants are shown in Tables 1 and 2. The nutrient content is in case of SSC addition elevated, e.g. the amount of nitrogen increases up to 0.97%. The main part is bound in the organic matter. The threshold values of the pollutants do not exceed the limit values of the German soil protection order (BBodSchV 1999).

Table 1. Chemical characteristics of the SSC – nutrients.

Parameter	Addition of SSC in Vol-%			
	0	50	75	
pH		7.5	7.3	7.4
Content of salt	mg/100g	46.1	105	177
OM	%	0.40	9.30	21.60
N _t	%	0.02	0.51	0.97
NH ₄ -N	mg/100g	0.12	1.06	1.97
NO ₃ -N	mg/100g	0.07	0.45	2.11
C _t	% TS	0.23	6.29	13.67
C/N		11.5	12.3	14.1
P	mg/100g	1.6	56.0	79.1
K	mg/100g	6.4	59.9	101.0
Mg	mg/100g	6.4	87.8	104.0

Table 2. Chemical characteristics of the SSC – pollutants.

Parameter	Addition of SSC in Vol-%				
	0	50	75	100	
As	mg/kg	5.2	5.3	5.2	4.4
Ni	mg/kg	33	23	29	20
Pb	mg/kg	9.5	22	18	43
Cr	mg/kg	49	48	48	77
Cu	mg/kg	11	37	35	87
Cd	mg/kg	<0.1	0.18	0.17	0.5
Hg	mg/kg	0.01	0.047	0.05	0.21
Zn	mg/kg	86	150	170	310
Σ PCB	mg/kg	n.d.			n.d.
Σ PCDD/PCDF	ng TE/kg	0.1			10
Σ PAH	mg/kg	0.06			1.89

Physical characteristics of the dump covering substrate are important for the water balance too. Therefore, a specific vegetation-test with sunflowers was carried out. The measured field capacity of the substrate was about 49% Vol-% and the plant available water was about 39 Vol-%. This means that the substrate has a high water storage capacity and is able to store huge amounts of precipitation, which leads to the reduction of seepage water (Tauchnitz 2006).

Results

During the two year field trial period, the NO₃-N and NH₄-N concentrations in the seepage water decreased markedly (Figure 1). For example, the SCC-variant with the 50 Vol-% addition showed a significant reduction of the NO₃-N concentration in the collected seepage water from the initial 1200 mg/L to a maximum of 200 mg/L. Regarding the NH₄-N leaching, the 75 Vol-% variant showed at the beginning a significantly lower concentration than the 50 Vol-% variant.

The additional outdoor laboratory experiment showed considerable differences in seepage water between the variants. The SSC variant with 50 Vol-% addition stored more water than the variants with 75 Vol-% SSC. The influence of preferential flow can be verified by regarding the 75 Vol-% variants. The influence of the vegetation on the water balance is remarkable. *Dactylis glomerata* as a perennial plant reduced the seepage water down to 50%. Another crop which also can reduce the amount of seepage water and is recommended for planting at the recultivation layer is *Zea mays*. In comparison to the field trials, the outdoor laboratory experiments also showed a remarkable reduction of the NO₃-N and NH₄-N concentrations during the test period.

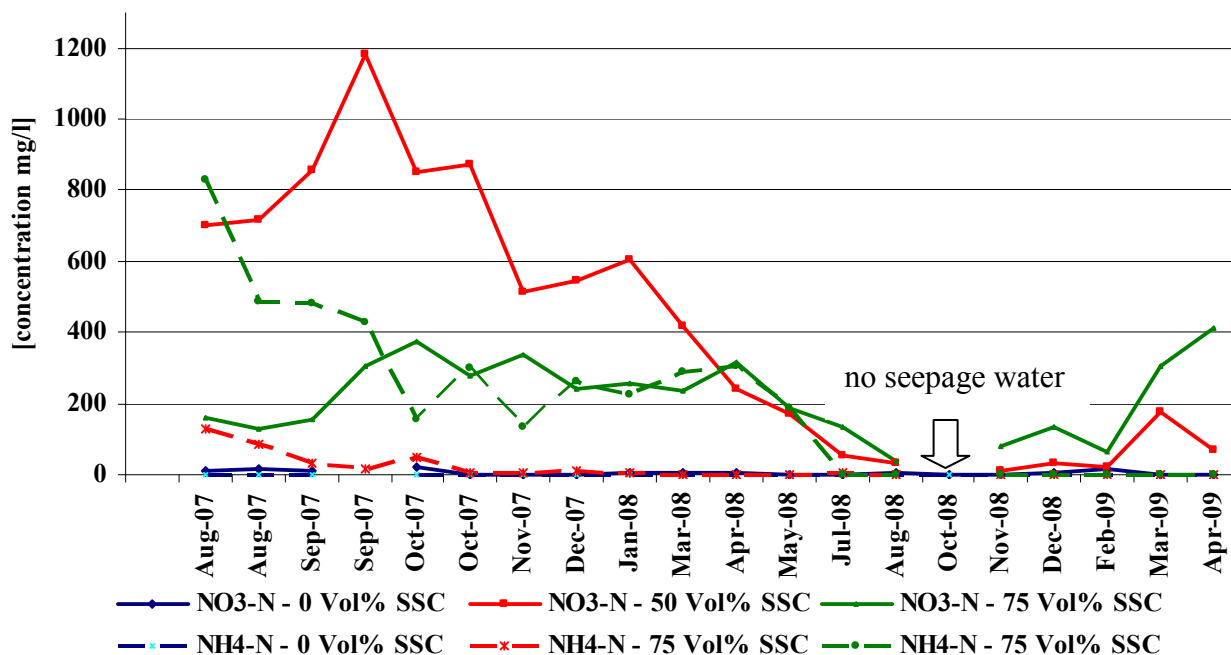


Figure 1. Concentration of NO₃-N and NH₄-N in the seepage water during the trial period.

Conclusion

The use of SSC in combination with a sandy soil can be recommended as a covering substrate for the recultivation of potassium mining waste dumps. The field capacity of the recultivation layer was elevated by mixing SSC with a sandy soil and consequently a higher amount of precipitation can be stored in this layer. After about one year, a significant reduction of the NO₃-N and NH₄-N concentrations in the seepage water was visible. The tested recultivation layers allowed the establishment and acceptable growth of plants which was connected with a reduction of the amount of seepage water. Further experiments are scheduled to refine the detailed construction of the recultivation layer as well as the use of the produced biomass for the production of renewable energy.

References

- Bernsdorf S, Tauchnitz S, Liemen F, Meißner R (2008). KA Korrespondenz Abwasser, Abfall, Nr. **55**, 1323 – 1328.
- Bundes-Bodenschutz- und Altlastenverordnung (BBodSchV) (1999). BGBl.I, Nr. **36**, 1554 – 1582.
- Gomiscek, T. (1999). Revegetation of closed landfills on diverse refuse substrates with fuel plants regarding the growth rates and water balance. Ph.D. Thesis, University of Natural Resources and Applied Life Sciences, Vienna.
- Knappe S, Haferkorn U, Mattusch J, Meissner R, Rupp H, Wennrich R (2004) Water and solute balances in recultivated lignite mining dump soils – field data and lysimeter experiments. *Water, Air and Soil Pollution* **157**, 85-105.
- Richtlinie für die Abdeckung und Begrünung von Kalihalden im Freistaat Thüringen, Kali-Halden-Richtlinie (2002). *ThürStAnz Nr. 19*, 1539 – 1560.
- Tauchnitz S (2006) Untersuchungen zum Wasserhaushalt und Stickstoffumsatz von Rekultivierungsschichten aus Klärschlammkomposten. Ph.D. Thesis, Martin-Luther-University Halle-Wittenberg.

Red pepper coverage effect on soil erosion by different transplanting dates

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Abstract

The study was carried out to evaluate the crop coverage effect on soil erosion as affected by different transplanting times under heavy rainfall. It was conducted at lysimeters having slopes of 15%, and length of 5 m, width of 2 m with three soil textural types, which were transplanted red peppers (*Capsicum annuum* L.) on May 4(RPI), 15(RPII), and 25(RPIII). Crop coverage for the plot was calculated by NDVI and crop heights measured at interval of 7 days. After the rainfall event, the runoff volume and soil erosion from the each plot was measured. Under heavy rainfall over 100mm, crop coverage of red pepper and soil erosion ratio were related ($p < 0.05$), depending on textural types. The coverage effect of red pepper transplanting time on runoff was different according to EI_{30} , rainfall with under 100 MJ mm /ha/h EI_{30} , affected runoff, but over 100 MJ mm /ha/h EI_{30} , it was not effective. Red pepper coverage effects on soil erosion partly depend on soil texture, and red pepper coverage effects on runoff depend on rainfall types.

Key Words

Soil erosion, crop coverage, soil texture, rainfall, red pepper.

Introduction

Upland in Korea is mainly slope land, and there is much heavy rainfall in summer, causing soil erosion. The surface coverage effect by crops is effective in protecting soil erosion. It could be that soil surface cover by vegetation increases infiltration of rainfall by increasing porosity, decreasing the striking power of falling raindrop and velocity of flowing water and consequently diminishes runoff and soil loss (Wainwright *et al.* 2000). In this study, our aim was to investigate the effect of red pepper transplanting time and coverage on soil erosion under lysimeters.

Materials and methods

The study was conducted at the lysimeter of the National Academy of Agricultural Science (NAAS) from May to August, 2009, which had 15% slope with length of 5m, width of 2m, having three textural type, clay loam, loam and sandy loam. Red pepper (*Capsicum annuum* L.) were transplanted on May 4, 15 and 25, indicated 'RPI', 'RPII', 'RPIII' respectively. After each rainfall event, runoff volume and soil erosion of each plot were measured. Rainfall data were obtained from meteorological information portal service system. EI_{30} was calculated using RUSLE (Renard *et al.* 1997). The procedure was:

$$EI_{30} = \Sigma(KE \times R) \times I_{30} \text{ (MJ mm /ha/h)}$$

$$KE = 0.119 + 0.0873 \log I$$

Where KE is the kinetic energy (MJ/ha/mm), R is rainfall amount(mm) and I is rainfall intensity(mm/h).

Canopy cover which is a RUSLE subfactor was calculated by using Normalized Difference Vegetation Index and canopy height estimated at intervals of 7 days from the lysimeter plot. As crops grow, the value of NDVI is higher and canopy cover is lower. Relationships between canopy cover, soil erosion ratio and runoff ratio were analyzed by using SAS statistics.

Results and discussion

Rainfall Events were classified as two types on the basis of EI_{30} . There were 2 events of type one (I) rainfall for which EI_{30} was lower than 100 MJ mm /ha/h, 131 mm in rainfall, 79.43 MJ mm /ha/h for EI_{30} and 145 mm in rainfall, 67.01 MJ mm /ha/h for EI_{30} , respectively. Type(II) rainfall was higher than 100 MJ mm /ha/h EI_{30} , i.e., 273.5 mm rainfall, 303.34 MJ mm /ha/h for EI_{30} and 101.3 mm in rainfall, 139.88 MJ mm /ha/h for EI_{30} . For this time crop coverage range was 16.8-58.3% on the plot with clay loam soil, 13.3-58.3 on the plot with loam soil and 17.9-59.6% on the plot with sandy loam soil. Canopy cover was calculated using crop coverage and crop height. Soil erosion ratio and canopy cover were correlated, but not having high R-Squared, but when sorted by texture, they were correlated having higher R^2 . Soil erosion ratio to plot with

bare soil was higher with canopy cover for the plot with clay loam soil. Soil texture had an influence on crop coverage effect on soil erosion under heavy rainfall over 100 mm. Runoff ratio for a plot with bare soil and canopy cover were not correlated, but on being sorted by rainfall type, they had relationship for rainfall type (I). Under the rainfall type(II), they had no relationship. It was anticipated that crop coverage by red pepper was not effective in reducing runoff under heavy rainfall, higher than 100 MJ mm /ha/h EI₃₀.

Table 1. Regression of soil erosion ratio(Y) with canopy cover(X) and runoff ratio(Y) with canopy cover(X) according to different textures and rainfall types. Soil erosion ratio means that eroded soil mass of RPI, RPII, RPIII divided by that of bare soil. ‘Rainfall type I’ is under 100 MJ mm /ha/h EI₃₀, and ‘rainfall typeII’ is over 100 MJ mm /ha/h EI₃₀.

		Regression	R ²
Soil erosion		Y=1.47368x-44.85533	0.3543 **
Texture	Clay loam	Y=2.59205x-111.64204	0.8307**
	Loam	Y=0.64448x+0.49345	0.4264 (ns)
	Sandy loam	Y=2.33658x-99.18761	0.4770*
Rainfall	I	Y=0.97209x-27.64524	0.1148 (ns)
	II	Y=1.29047x-35.04603	0.3132*
Runoff		Y= 0.56479x+ 47.60506	0.0849(ns)
Texture	Clay loam	Y= 0.76025x+ 42.52626	0.2116(ns)
	Loam	Y=0.30103x+55.67837	0.0454 (ns)
	Sandy loam	Y=1.10190x+13.18546	0.1451 (ns)
Rainfall type	I	Y= 1.35040x -13.73805	0.3356*
	II	Y= -0.14044x+ 102.00995	0.0114 (ns)

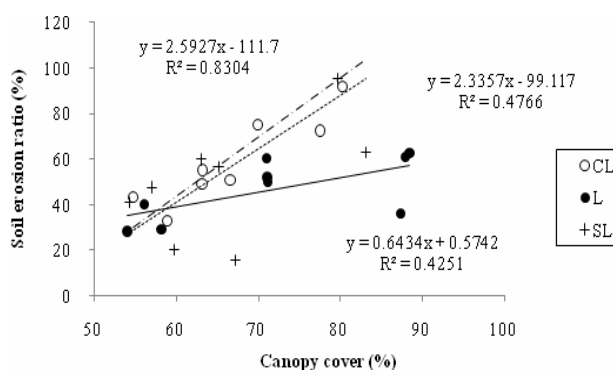


Figure 1. The effect of canopy cover on soil erosion ratio in plots with clay loam, loam and sandy loam soil.

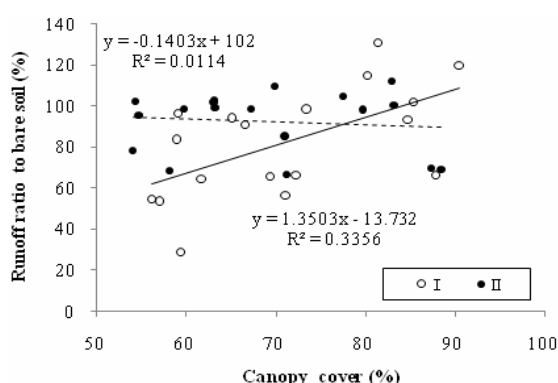


Figure 2. The effect of canopy cover on soil erosion ratio for rainfall types. Rainfall type II has the higher EI₃₀.

Conclusion

Coverage of red pepper with different transplanting times and soil erosion was related ($p < 0.01$), depending on soil texture. Particularly the trend was higher for the plot with the loam soil than for other plots when under heavy rainfall. The coverage effect on runoff was different according to rainfall type. For rainfall under 100 MJ mm /ha/h EI₃₀, crop coverage by transplanting date was effective on runoff. For rainfall over 100 MJ mm /ha/h EI₃₀, it was not. Consequently, the crop coverage effect on runoff was related to rainfall, but more experimental data would be needed to set the critical point of EI₃₀ provide to cover effect.

References

- Renard KG, Foster GR, Weesies GA, Mc Cool DK, Yoder DC (1997) 'Predicting soil erosion water: A guide to conservation planning with the revised universal soil loss equation(RUSLE)'. Agric. Handbook No. 703. (USDA: Washington DC).
- Wainwright J, Parsons AJ, Abronbams AD (2000) Plot scale studies of vegetation, overland flow and erosion interaction s: case studies from Arizona and New Mexico. *Hydrol. Process* **14**, 2921-2943.

Research on soil desalinization through platform fields and by irrigation using sea-ice water

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Abstract

Saline soil damage is a major limiting factor of high-yield agriculture in the coastal soil-salinization region in China. Results indicate that the comprehensive land use pattern of elevated-platform-fields and shallow-pond reduced the saline soil damage effectively. The desalinization efficiency is up to 52% of original salt content by used of building platform-fields in Huanghua city of Hebei province in China. The desalinization efficiency was also notable for using sea-ice water to irrigate during the crop growth stages. For example, irrigating by using low mineral sea-ice water in July had a better desalinization efficiency, with a total desalinization volume up to 2.7 g per one cubic meter sample area, with the relative quantity was 6.2 g as compared to the un-elevated barren-salinized land and 3.8 g as compared to the non-irrigation elevated-platform fields, respectively, which means the desalinization efficiency extent of the elevated-platform fields (compared to un-elevated barren-salinization land) was better than the desalinization efficiency by sea-ice water irrigation (compared to non-irrigated areas). This research impacts the establishment of desalinization systems using elevated-platform fields and shallow pond pattern in coastal barren-salinization land area, but also the safe application of sea-ice water to the agriculture irrigation.

Key Words

Elevated-platform fields, shallow ponds.

Introduction

There are large amounts of saline land in China. Statistics show that China's salinization soil area is 2.7×10^5 km², of which 6.67×10^4 km², or 7% of the total, is used for agricultural (Wang 2007). Shi Yuan-Chun proposed the integrated management of saline soil to achieve regional resistance to drought and flood and the elimination of soil salinization through regulation and management of regional water movement (Shi *et al* 1986; Marlet 2009). An effective way is to establish a "water net" and "tube-well project" for reducing groundwater levels, so that the arable layer is kept away from the high saline groundwater, and eventually achieving the salt reduction and water sustainable use; but one of its disadvantages is the drainage requires a long-term, sustained process, and the latter part of pipe network maintenance is costly. The precipitation in the coastal area is concentrated in the summer, and it is very easy to form flood conditions, since drainage is slowed. It can cause salt accumulation that can move upward, thus affecting land quality. Its second drawback is that large amounts of fresh water are required for irrigation to achieve soil desalinization, thus this method is not suitable for areas that have shortages of freshwater. In China, we faced a new challenge regarding saline soil reclamation by using limited freshwater resources (Huang 2003).

Saline soil injury is mainly found in the coastal region, whether the land-use patterns are reasonable directly affects the soil salinity change and re-distribution of soil salinity, furthermore affecting the grain yield and land security. Mao-Tuo village in Dongying City, Shandong Province began to carry out soil improvement projects since 1996, due to aggressively using the Yellow River to elute soil salt. Almost all the lands in the village had completed engineering transformations by 2007. The former salty fields now can be planted grapes, melons, fruits and other high-income economic crops, and per hectare income increased to 90,000 yuan. The successful experience of Dongying has great guiding significance (Zhang 2008), showing the distinct advantages of integrated land use management patterns of elevated-platform fields and shallow ponds: 1) the post-maintenance costs are very low, and 2) significantly reduced risk of floods. This guarantees the security of arable layer. After successful research and development of desalination of sea-ice water resources (Shi *et al.* 2002 ; Gu *et al.* 2003), experts Shi Pei-Jun and Gu Wei provided valuable water resources for the soil salty-eluting in coastal region. The comprehensive land use improvement models of elevated-platform fields and the sea-ice water resources utilization make it possible for barren-soil transformation, which is impossible in the past. Xiao Jian-guo (Xiao *et al.* 2003) and other experts' studies have shown that field crops can grow normally or even increase production under the condition of 3g/L the

sea-ice water irrigation, but the experiments should be based on light-saline soil conditions (salt content of 1 g/L or so). However, their studies don't give enough considerations to the regional suitability of agricultural irrigation (Wang 2003) and researches on the long-term sustainable safe utilization of sea-ice water resources are also insufficient. The comprehensive land use improvement models of elevated-platform fields and sea-ice water resources utilization will be quite different from the traditional land use patterns. Therefore, the comprehensive desalinization land use models of elevated-platform fields and sea-ice water resources irrigation is of great significance to the coastal heavy-salinity land area.

Methods

Profiles of the experimental area

Huanghua, a coastal city of Hebei province, is located at latitude 38° 09' N~ 38° 39' N longitude 117° 05' E~ 117° 49' E, with a total area of 2.25 km². Its soil salt is mainly from sea water, with the deposition of sea saline sludge occurring directly from exposure to the coastal saline waters, its soil surface has a high salt accumulation and soil profile also is very highly saline. Therefore, the experimental area is a heavy-saline wasteland, which has been excluded from many soil improvement programs in the past. The sample elevated-platform fields were built in 2007.

Experimental Designs and Methods

For better reference, we chose three comparable sample areas, they are: the Mao Tuo Village of Dongying city, the 11th Sino-Czech farm in Huanghua city, the Sino-Czech celebrity golf court of Huanghua city, based on salt analysis of earth samples in these three sample areas. As to the elevated-platform fields of the 11th Sino-Czech farm in Huanghua city, during the seeding growth period of May 21 and grain-filling stage of July 16, applied 3 g/L and 1.6 g/L sea-ice water to irrigate respectively, two irrigation volumes are both 375 m³/km². Soil solution extracted by using 5:1 water:soil ratio, using the DDBJ-350-type conductivity device to measure the conductivity of extracted liquid, finally obtained soil salinity through the standard curve. Through the comparative analysis of soil-salinity volume changes between the elevated-platform fields and waste salt-land, can get their differences soil salt-drainage contribution volume.

Results

Distribution of soil salinity of elevated-platform fields in different regions

Surface soil salinity of waste salt-land in Huanghua and Mao Tuo are both very high, soil salinity shows a decrease trend with the increase of soil layer depth, and the downward trend gradually slowed down; on the contrary, the surface soil salinity of the elevated-platform fields in two regions showed a lower soil salinity, and with the increase in soil depth, its soil salinity increased slightly. A significant phenomenon can be found that, surface soil salinity of waste salt-land (0-20 cm depth) is 15.2 g/kg, while the corresponding salinity of the elevated-platform fields layer of Mao Tuo is just 1.7 g/kg, which means the desalination efficiency of the elevated-platform fields extends to 89% in Mao Tuo. There is a similar phenomenon in Huanghua sample area: surface soil salinity of waste salt-land (0-20 cm depth) in Huanghua is 5.9 g/kg, while the corresponding salinity of the elevated-platform fields layer of Huanghua is only 3.1 g/kg, the desalination efficiency of the elevated-platform fields in Huanghua up to 47%. As to the Sino-Czech celebrity golf court of Huanghua, after two years' mechanical soil-elevated and greening projects, the soil salinity of the plow layer dropped to 2g/kg below which soil-saline injury is almost eliminated.

Distribution soil salinity of the elevated-platform fields under different irrigation treatment

Figure 1 (a) shows that soil salinity of 0 ~ 10cm soil layer of Huanghua increased to 14 g/kg in July 22, 2009. Find the waste salt-land surface experienced a strong salt accumulation process along with the weather change, but the 20 ~ 100cm soil layer is within 4 ~ 6 g/kg mainly controlled by ground water, so the change is relatively stable. Figure 1 (b) shows the salinity change rules of non-irrigation treatment elevated-platform fields, soil salinity showed mainly a gradual increasing trend from 0 cm to 120cm soil layer, while a reducing trend from 120 cm to 240 cm, this is because the salt migrated from the soil surface to deep soil layer; at the same time, the shallow groundwater transported salt upward due to its inner capillary tension, these two processes join together to form the phenomenon of salt accumulation (Shang 1985; Li 1988). Associated with Figure 1 (a), can find the non-irrigation treatment elevated-platform fields is not like the waste salt-land, which has a strong surface salt accumulation process. Figure 1 (c) shows that: salinity of 0 ~ 100cm soil layer under 3 g/L sea-ice water irrigation treatment increased slightly from May 21 to June 23, basically being maintained within 4-6 g/kg. After the 1.6 g/L of the sea ice water irrigation treatment in July 16, it shows a significant desalinization process, until July 22, the soil salt-accumulation layer appears in

180cm depth, compared with Figure 1 (b) shows that the accumulation layer of soil salinity has moved down by 60 cm, which shows a notable desalination efficiency under sea-ice water irrigation treatment.

Desalination efficiency of elevated-platform fields compared with the waste salt-land

Salt of the surface soil(0-40cm) in waste salt-land increased by $5,721 \text{ g/m}^3$ within two-months of June and July, while the corresponding Salt volume in non-irrigated elevated-platform fields decreased by 923 g/m^3 , the relative desalination is $5,211 \text{ g/m}^3$ as to the waste salt-land; the desalination of 1.6 g/L sea ice water irrigation treatment in elevated-platform fields is 899 g/m^3 , with a relative desalination of $5,186 \text{ g/m}^3$. Analysis shows the significant desalination efficiency of the elevated-platform fields.

Analysis of salt-drainage contribution difference between the elevated-platform fields and sea-ice water irrigation

In Figure 2 (g) and (h), notice that: salt-drainage effect of 1.6 g/L sea-ice irrigation treatment can reaches depth of 120cm, while the salt-drainage effect of elevated-platform fields treatment reaches depth of 2 m or so; as to the salt-drainage contribution rate comparison of these two treatments is also interesting: within 0-100cm soil layers, the elevated-platform fields treatment is much notable than the 1.6 g/L sea-salt irrigation treatment, while salt-drainage effect of the latter is more notable when below 100 cm. Comparing (g) and (h) of Figure 2: salt-drainage contribution rate of the elevated-platform fields treatment is better than sea-ice irrigation treatment, the 3 g/L sea-ice irrigation plays a negative role to the salt-drainage from May to June, which strengthening the risk of soil-saline injury, while in the period of July and August, the sea-ice irrigation treatment achieved a better salt-drainage effect.

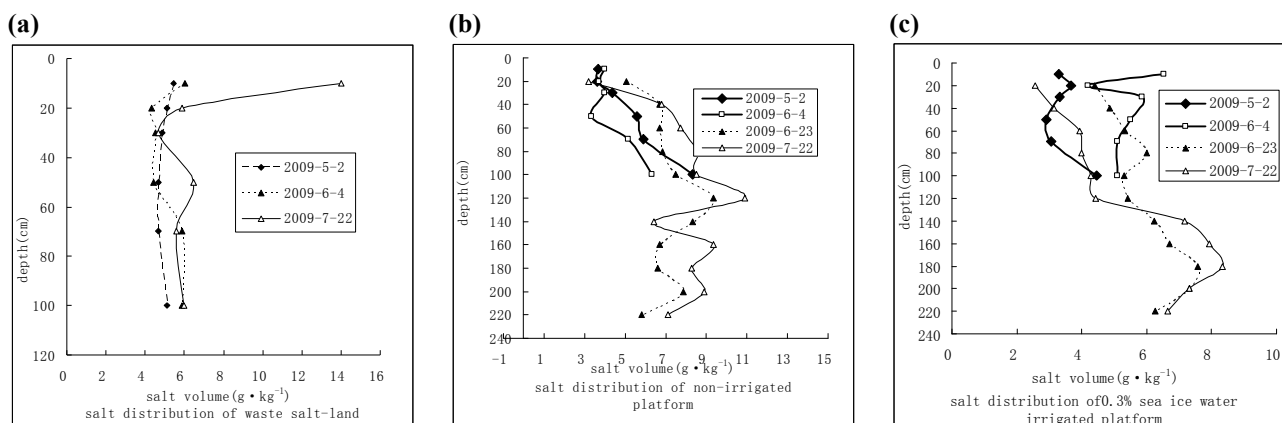


Figure 1. Platform soil layer salt distribute regulation under different irrigation (2009).

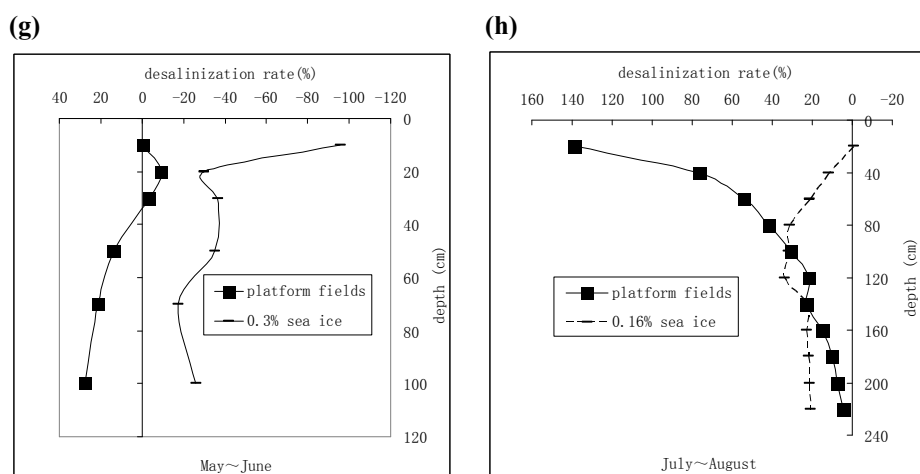


Figure 2. Desalination analysis of platform fields and sea-ice irrigation (2009).

Discussion

Salinity of the waste salt-land in Huanghua and Mao Tuo both show a decreasing trend with the increase of soil layer depth, and the downward trend gradually decreased; on the contrary, salinity of the elevated-platform fields in two regions show a increasing trend with the increase of soil layer depth. This conclusion

shows the desalinization efficiency of the elevated-platform fields is remarkable especially to the surface arable soil layer which effectively decreases the saline injury risk to vegetation.

Soil salinity of non-irrigation treatment shows little changes with depth increase, in which the total salt of 0-60 cm soil layer decreased slightly, salt of below 60 cm shows a slight increase, among one unit area of 0-220 cm depth soil, its total body salt increased 748 g/m³. It indicates that the 2 m elevated-platform fields can effectively prevent or mitigate the salt increase phenomenon, if coupled with effective irrigation; it can distinctly achieve the goal of decrease salinity or salt-drainage. While on the contrary, the usage of 3 g/L sea-ice water for irrigation in heavy-saline area may cause salt accumulation and even the destruction of soil texture. Although many studies have shown that irrigation using 3g/L sea-ice water may play a role of increasing production, but due to the salt-transport laws of soil itself, irrigation during May or June using 3 g/L sea-ice water can cause a higher risk of salt accumulation injury.

The 2 meter elevated-platform fields shows a notable desalinization efficiency in heavy-saline soil area, salt-drainage contribution rate of the elevated-platform fields ups to 138.9% during July and August, using 1.6 g/L sea-ice water for irrigation can help to promote the salt-drainage effect. So in heavy-saline soil area, salt-drainage contribution rate of the elevated-platform fields is far greater than the sea-ice water irrigation treatment. In other words, relying on the desalinization efficiency of elevated-platform fields and combining with the local seasonal precipitation patterns, can rational allocate different concentrations of sea-ice water to agriculture irrigation in different periods: in the spring, the primarily purpose of using sea-ice water for irrigation is to promote the growth of the seedling, while during the summer, the purpose of using sea-ice water for irrigation is mainly for salt-drainage. Considering these differences at different periods, we need to make sure that the saline-soil improvement by salt-drainage methods in coastal barren-saline region is sustainable and will lead to good land use.

References

- Gu W, Gu S, Shi P, Liu Y, Cui W (2003) The temporal change characteristics of sea ice thickness and regeneration period of sea ice in Liao-Dong Gulf. *Resources Science* **25**,24-32.
- Huang R (1985) 'Water Resources and Soil Improvement of China Saline-Alkali Wasteland' (China Agricultural University Press).
- Li T, Zheng Y, Wang Y (1983) 'Soil Geography, Version 2' (Higher Education Press).
- Li Y (1988) Discussion on critical depth of groundwater and its determinative method. *Journal of Xi'an College of Geology* **10**, 100-105.
- Marlet S, Bouksila F, Bahri A (2009) Water and salt balance at irrigation scheme scale a comprehensive approach for salinity assessment in a Saharan oasis. *Agricultural Water Management* **961**, 311-1322
- Shang D (1985) Calculating of groundwater critical depth in North of NingXia Area. *Ground Water* **4**, 10-12.
- Shi P, Ha S, Yuan Y, Zhou J, Xie F (2002) The desalinization of Bohai Sea Ice and its use value as fresh water resource. *Journal of Natural Resources* **17**, 353-359.
- Shi Y, Li, Y (1986) Progress in the study of water and salinity transport in soils. *Arid Zone Research* **4**, 38-44.
- Wang J (2007) 'China Geography Tutorial'. (Higher Education Press).
- Wang J, Su Y, Liu M (2003)The exploitation and utilization of the ice in Bohai sea used as freshwater resources and region sustainable development. *Journal of Beijing Normal University (Social Science)* **87**, 85-72.
- Xiao J, Xie L, Wang J, Feng G, Shi S (2003) Effects of the Bohai Sea ice melt-water on wheat growth and soil salt accumulation. *Resources Science* **25**, 37-43.
- Zhang X (2008) Exploration on agriculture-fishery development mode in saline-alkali soil of Yellow River Delta. *Journal of Hebei Agricultural Sciences* **12**, 116- 117.

Soil physical and biological properties as influenced by growth of vetiver grass (*Vetiveria zizanioides* L.) in a semi-arid environment of South Africa

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Abstract

The influence of 15-years of vetiver grass growth on soil quality was assessed by measuring physical and biological properties which were compared with adjacent lands that had been under natural fallow and continuous grazing. Soil properties were better under grass than non-grassed control. Soil in plots under vetiver grass was consistently of better quality than that under natural fallow grass. Increased soil organic matter and microbial biomass contents were considered to be responsible for the improved quality on soils under grass than control plots. The improvement in soil properties was more pronounced under vetiver than natural grass. It is concluded that higher organic matter input from vetiver grass residues and roots, exudation of organic compounds from roots and a large microbial biomass in the rhizosphere of vetiver grass contributed to the improvement in soil properties. The use of vetiver grass is recommended as an affordable and sustainable soil management practice to improve soil quality.

Key Words

Soil quality, soil erosion, land degradation, sustainable soil management, semi-arid areas

Introduction

Soil erosion is a serious land degradation problem threatening the productivity and sustainability of many South Africans' arable lands especially in semi-arid areas (Hoffman and Ashwell, 2001). The use of vetiver grass is one strategy that is actively being promoted as a means to rehabilitate eroded soils worldwide (Pang *et al.*, 2003). In 1993, the provincial Department of Water Affairs and Forestry (DWARF) established plots (about 1.5 ha) of vetiver grass on an agricultural land that had been exposed to severe erosion overtime. A land adjacent to the vetiver plot was left under natural fallow grass (*Cynodon dactylon* and *Eragrostic species*) for the same period of time. Both plots were fenced to prevent any disturbance and protected from fire. The objective of this study was to evaluate the ability of vetiver grass to restore soil quality when compared with natural grass. A plot without any grass (non-grassed) was used as a control.

Methods

The study was conducted in July 2008 at Danville, a site located about 2 km outside the city of Mafikeng (longitude 25°48' S, latitude 25°38' E; 1218 m asl) in the North West Province of South Africa. Mafikeng has a typical semi-arid tropical savanna climate and receives summer rainfall with an annual mean of 571 mm. The surface (0-20 cm) soil at the site is a brown to dark reddish brown sandy loam classified as Hutton form according to the South African soil classification system (Soil Classification Working Group, 1991) and has characteristics similar to a Chromic Luvisol.

For purposes of statistical analysis, each of the three one hectare plots (vetiver grass, VG; natural grass, NG; non grassed control, CC) was divided into three equal sub-plots which were used as replicates. Soil samples were collected from five randomly selected positions within each replicate using a spade to a depth of 0-15 cm. The sub-samples from each replicate were mixed thoroughly to make one composite sample on which the analyses of the physical and biological properties of the soils were conducted to determine quality. For the fractionation of particulate organic matter and determination of microbial biomass, fresh subsamples were kept in airtight plastic bags and stored in a refrigerator. The rest of the samples were air dried. Samples for the determination of soil water retention were collected in cylindrical metal rings.

Physical properties

The distribution of aggregate sizes was determined by the method of Kemper and Rosenau (1986). Aggregate stability was determined using the wet-sieving technique. Bulk density was determined using the clod method. Soil water retention was determined at two soil water potentials (-33 and -1200 kPa) using the standard pressure plate apparatus. Soil penetration resistance was measured using a hand held cone type proving ring penetrometer model 29-3739 with a cone diameter of 6.2 mm. Gravimetric soil moisture content was determined by drying sub-samples of the soil in the oven at 105°C for 24h.

Biological properties

Soil organic carbon was determined using the wet oxidation method. Physical fractionation of soil to collect the particulate organic matter (POM) fraction was conducted using a modification of the method described by Okalebo *et al.* (1993). Microbial biomass was determined on fresh samples by the chloroform extraction method (Vance *et al.*, 1987).

Analysis of data

Since the treatments in the original set up were not properly replicated or randomized, the results are presented using means and standard deviations. Significant differences among treatment means were tested using by the least significant difference at $p=0.05$ (Steel and Torrie, 1980).

Results and discussion

Table 1 show that the soil in plots of both vetiver (VG) and natural fallow (NG) grass had more improved structural conditions compared to that without grass (CC). The former had significantly lower ($P<0.05$) bulk density, penetrometer resistances and smaller aggregate sizes but had significantly higher ($P<0.05$) soil water content and retention properties. Within the grass species however, the soil with vetiver grass had better properties than that under natural grass. Similar observations were made with respect to soil biological properties (Table 2). The organic C, POM, microbial biomass C and microbial quotient were highest in VG and lowest in CC while that for NG was in the middle. The microbial quotient ranged from 1% to 4% which is in the range commonly found in soils. Table 3 shows that organic matter and particulate organic matter were the most conspicuous soil properties that were influenced by the presence of grass in the plots and these were also strongly correlated with a wide range of other soil properties.

The higher organic carbon content in the plots with grass suggests higher organic matter inputs from litter originating from above and below ground parts of the grass. The humus which is produced after decomposition, binds to soil minerals to form soil aggregates that are stable thereby improving soil porosity, aeration and the water-retention capacities of the soil (Haynes, 1999). It has been well established from many parts of the world that organic matter has a profound influence on many soil properties and is therefore a key attribute of soil quality (Gregorich *et al.*, 1994). The higher aggregation and stability of aggregates in vetiver plots is likely due to the influence of extensive mat of fine roots and microbially produced polysaccharides associated with the rhizosphere of the vetiver grass (Pang *et al.*, 2003). This implies that the aggregates and pores in this soil will remain undamaged on exposure to stress arising from raindrop impact thereby improving the movement and storage of water, air and biological activity, and growth of crops.

It was interesting to note the significant relationship between POM, microbial biomass C and the other soil properties. Both POM and microbial biomass are the labile non-humic fraction of organic matter and therefore constitute important pools of nutrients in the soil (Stevenson, 1994). The POM fraction hosts a large concentration of microorganisms because it provides a substrate for their activities (Janzen *et al.*, 1992). The soil microbial biomass is thus important in maintaining soil structure in that the microorganisms associated with it exude mucilaginous carbohydrate material which acts as a glue and helps cement soil aggregates together (Dalal, 1998).

Conclusion

It is evident that vetiver grass had an ameliorative effect on soil quality under the semi-arid conditions of South Africa. It not only increased the soil organic matter in the surface soil, but also improved the physical and biological properties which are important for crop production and the environment in general. Its use for soil conservation is therefore recommended.

References

- Dalal RC (1998) Soil microbial biomass-What do the numbers really mean? *Australian Journal of Experimental Agriculture* **38**, 649-665.
- Gregorich EG, Carter MR, Angers DA, Monreal CM, Ellert BH (1994) Towards a minimum data set to assess soil organic matter quality in agricultural soils. *Canadian Journal of Soil Science* **75**, 161-167.
- Haynes RJ (1999) Labile organic matter fractions and aggregate stability under short-term grass-based leys. *Soil Biology and Biochemistry* **31**, 1821-1830.
- Hoffman T, Ashwell A (2001) Nature Divided: Land Degradation in South Africa. (University of Cape Town Press: Cape Town).

- Janzen HH, Campbell CA, Brandt SA, LaFond GP, Towney-Smith L (1992) Light-fraction organic matter in soils from long-term crop rotations. *Soil Science Society of America Journal* **56**, 1799-1806.
- Kemper WD, Rosenau RC (1986) Aggregate stability and size distribution. In 'Methods of Soil Analysis, Part 1. Physical and Mineralogical Methods'. (Ed. Klute A.) 2nd edn, pp. 425-442. (Soil Science Society America: Madison).
- Okalebo JR, Gathua KW, Woomer PL (1993) Fractionation of organic matter by particle size. In 'Laboratory Methods of Soil and Plant Analysis: A Working Manual'. (Eds Okalebo JR *et al.*), pp. 66-68. (TSBF-KARI-UNESCO: Nairobi).
- Pang J, Chan GSY, Zhang J, Liang J, Wong MH (2003) Physiological aspects of vetiver grass for rehabilitation in abandoned metalliferous mine wastes. *Chemosphere* **52**, 1559-1570.
- Soil Classification Working Group (1991) Soil Classification: A Taxonomic System for South Africa. Memoirs of Agric. Natural Resources of South Africa: Pretoria.
- Steel RGW, Torrie JH (1980) Principles and Procedures of Statistics: A Biometrical Approach, 2nd edn. (McGraw-Hill Book Co.: New York).
- Stevenson FJ (1994) Humus chemistry, Genesis, composition, reactions. 2nd edn. (John Wiley & Sons: New York).
- Vance ED, Brookes PC, Jenkeson DS (1987) An extraction method for measuring soil microbial biomass. *Soil Biology and Biochemistry* **19**, 703-707.

Table 1. Physical properties of the surface (0-15 cm) soil after 15-years under different grass species. Values are means (\pm SD).

Grass	Bulk Density (Mg m ⁻³)	Soil Water Retention (%)		Soil Water Content (%)	Penetrometer Resistance (kPa)	Aggregate Stability (%>2.0mm)	Aggregate Mean Weight Diameter, dry (mm)
		-33 kPa	-1200 kPa				
VG	1.23 \pm 0.11	17.32 \pm 1.02	13.44 \pm 0.97	15.78 \pm 2.43	386 \pm 43	65.4 \pm 5.1	3.2 \pm 0.10
NG	1.44 \pm 0.06	12.64 \pm 0.76	10.08 \pm 1.04	11.67 \pm 0.74	517 \pm 24	54.2 \pm 2.3	4.7 \pm 0.33
CC	1.68 \pm 0.75	8.13 \pm 0.48	5.06 \pm 0.12	9.15 \pm 1.26	829 \pm 55	21.6 \pm 8.1	7.8 \pm 0.45
<i>LSD (p=0.05)</i>	<i>0.19</i>	<i>3.77</i>	<i>3.26</i>	<i>2.33</i>	<i>125</i>	<i>9.6</i>	<i>1.44</i>

Table 2. Influence of vetiver grass on biological properties of a surface (0-15 cm) at Danville. Values are means (\pm SD).

Grass	Organic C (%)	POM (%)	Microbial Biomass C (mg/kg)	Microbial Quotient	Proportion of POM in whole soil (%)
VG	2.53 \pm 0.35	3.29 \pm 0.08	306 \pm 63	0.04	5.27 \pm 0.03
NG	1.64 \pm 0.56	2.67 \pm 0.15	218 \pm 24	0.02	3.32 \pm 0.44
CC	0.67 \pm 0.12	1.37 \pm 0.10	96 \pm 8	0.01	1.16 \pm 0.28
<i>LSD (p=0.05)</i>	<i>0.75</i>	<i>0.54</i>	<i>9.85</i>	<i>0.007</i>	<i>1.74</i>

Table 3 Some of the significant correlation coefficients estimated between the measured soil properties

	BD	POM	SWC	SWR	PR	AS	MBc
Organic carbon (OC)	-0.78**	0.85***	0.68*	0.53*	-0.61**	0.71**	0.89***
Particulate organic matter (POM)	-0.55*	-	0.51*	0.59*	-0.73	0.64*	0.87**

BD= bulk density; POM=particulate organic matter; SWC=soil water content, SWR=soil water retention; PR=penetrometer resistance; AS=aggregate stability; MBc= microbial biomass carbon; *, **, *** significant at the $P<0.05$, $p<0.01$, $P<0.001$ respectively

Soil solution chemistry and elemental balance of Fushan natural hardwood forest ecosystem in Taiwan

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Abstract

Studies of soil solution composition have been used as the means of improving knowledge of basic ecological characteristics of a study area. The objectives of this study were to determine the cations and anions in throughfall, surface runoff and soil solution and to estimate the elemental inputs and outputs in the Fushan subtropical Forest Dynamics Plot (Fushan FDP). Throughfall, surface runoff, and soil solution of A and B horizons were collected monthly for two years (January 1, 2007 to February 28, 2009) both in Inceptisols and Ultisols with 3 replicated soil profiles in each soil. During the study period, the mean pH of throughfall is 4.7, and is changed to 6.4 after it percolated into the soil pedon. The mean Ca concentration which is the dominant cation in the soil solution (341 $\mu\text{eq/L}$), was higher than in throughfall (20.9 $\mu\text{eq/L}$) and surface runoff (42.4 $\mu\text{eq/L}$). The higher Ca concentration in the soil solution could be one of the buffering mechanisms in Fushan FDP. The results also indicate that the ions of Si, Ca, Fe, and nitrate have larger output than those of input in the forest ecosystem, the loss of Al and Mn for the study site is limited, and the ions of K, Na, Mg, Cl, and sulphate are retained in the study site.

Key Words

Fushan forest dynamic plot, Soil solution, Throughfall, Soil elements, Nutrient budget.

Introduction

The chemical composition of the soil solution changes with time and space reflecting biological and chemical processes during transport and storage of the soil water (Tokuchi *et al.* 1993; Hseu and Chen 1996, 2000; Hseu *et al.* 2000). The soil solution is intermediary between input and output of forest ecosystems (Wu *et al.* 2007). Soil solution chemistry is strongly influenced by both soil properties and by the total load of atmospheric chemical input. The soil solution is intermediary between input and output of forest ecosystems (Baeumler and Zech 1998). The Fushan subtropical Forest Dynamics Plot (FDP), as the first subtropical 25 ha FDP, was established in northern Taiwan in September 2004 (Su *et al.* 2007). The forest within the plot is an old-growth montane rain forest which is composed of broadleaf trees, featuring lush ferns and epiphytes. Alpine and subalpine ecosystems are very sensitive to such influences, and we must understand the multiple interactions within mountain ecosystems after any kind of interference for future risk assessment or minimization. The objectives of this study are to characterize the element dynamics in the soil solution of mountain forest ecosystems of Fushan FDP, and the impact of acidic atmospheric deposition.

Methods

Study site

The Fushan FDP is located at 24 45'40"N, 121 33'28"E, and the plot is square in shape and measures 500 m (north-south) by 500 m (east-west) (Su *et al.* 2007) (Figure 1). The elevation of the Fushan FDP ranges from 600 m to 733 m above sea level. The topographic components of hills, ridges, slopes, gullies, flats, and the creek constitute a complex relief for the plot. The bedrock in this area is a metamorphosed sedimentary rock from the Oligocene and Miocene, containing argillite and slate (Tang and Yang 1976). The climate of Fushan FDP is strongly influenced by the northeastern monsoon in winter and by typhoon in summer, with an average temperature of 18.2°C, a mean annual precipitation of 4271 mm, and a mean relative humidity of 95%. In the first survey of the 25-ha Fushan FDP, 110 woody species belonging to 67 genera and 39 families were recorded. The total flora of the plot includes 328 vascular plant species of 206 genera and 92 families (Su *et al.* 2007).

Collection and analysis of throughfall, surface water, and soil solution

The former studies indicated that soils in the Fushan FDP are extremely acidic (pH 3.3~4.3) with low organic carbon content, low base saturation, and low soil fertility (Su *et al.* 2007). Two major soil groups can be found in the Fushan FDP, Dystrudepts (Inceptisols) and Hapludults (Ultisols). Inceptisols were mainly distributed on steep slopes and well-drained areas while Hapludults were formed only in the relatively level

portions of the plot. In this study, two sites each have three separate soil profiles are selected to understand the spatial variability, one is located on steep slope with Inceptisols, and the other is located at gentle slope with Ultisols (Figure 1). Throughfall, surface water, and soil solution of A (about 10 cm depth) and lowest layer of B horizon (about 60-100 cm depth) in each profile were collected monthly. The study period ranged from January 2008 to February 2009 (14 months). Throughfall, surface water, and soil solution of A and B horizons were filtered by Whatman No.42 filter paper, and the analyses of items, cations and anions are listed as: pH, EC, DOC (Total Organic Carbon Analyser, Aurora Model 1030W), Ca, Mg, K, Na, Fe, Al, Mn, Si (ICP-AES, Perkin-Elmer 2100 DV), and NO₃, PO₄, SO₄ and Cl ions (Metrohm, 792 Basic IC).

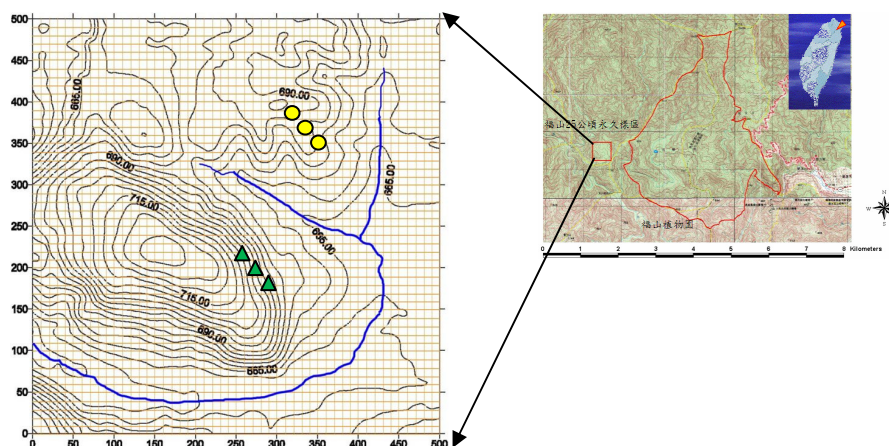


Figure 1. Location and the contour map of the Fushan FDP drawn with 5-m intervals in elevation. The axis labels denote the horizontal distance (m) from the southwestern corner of the plot. The blue line indicates the creek (Su *et al.* 2007). Sampling location of soil solutions are indicated by triangles for profiles of Inceptisols (I1, I2, and I3) and indicated by circles for profiles of Ultisols (U1, U2, and U3).

Results

Charge balance

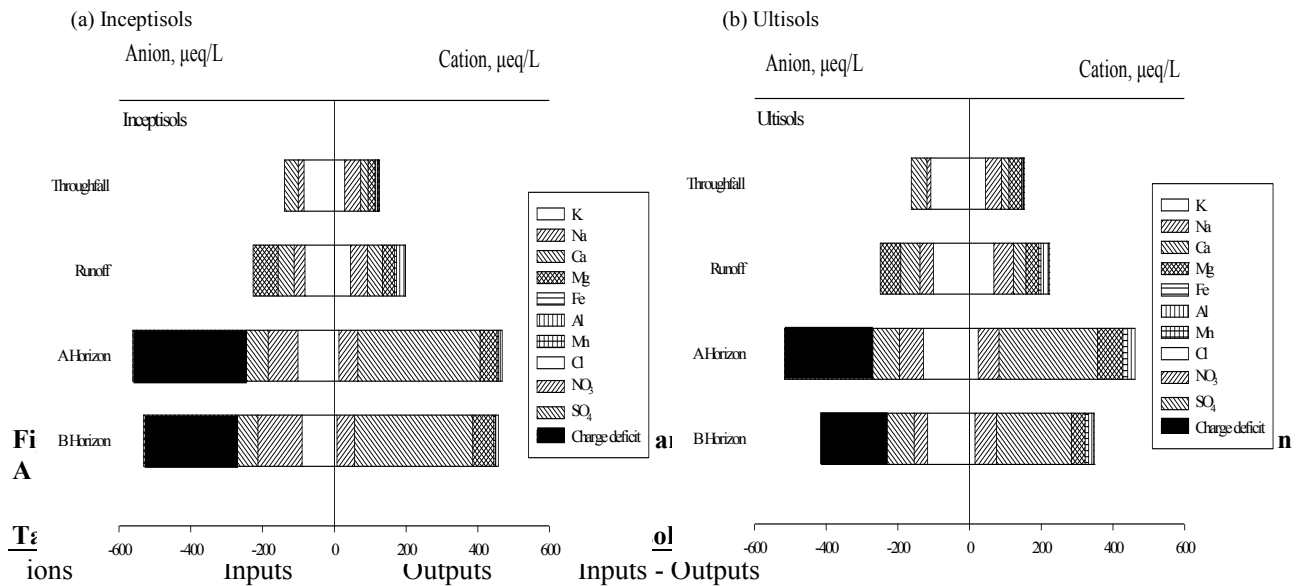
The volume-weighted equivalent mean the values of element concentration in throughfall, surface runoff, and soil solution of A and B horizons were showed (Figure 2). In general, total ion concentration of soil solution increased from throughfall to A horizon, and decreased from A to B horizon. The concentration of potassium ion (K) was in decreasing order: surface runoff > throughfall > soil solution. Berg and Staaf (1987) suggested that K ion is the most mobile cation, and it could be fast eluviated in the initial stage of litterfall decomposition. Highest K concentration in the surface runoff can be attributed to the decomposition of litterfall at soil surface. The rate of K cycling was fast, and K ion of soil solution was easily absorbed and reused by plant roots resulting in lower concentration in soil solution (Sposito 1984; Grimaldi *et al.* 2004). The concentration of Cl⁻ and Na⁺ ion are both higher in throughfall, surface runoff and soil solution. The mean equivalent concentration of soil solution ranged from 44 to 60 µeq Cl/L and 82 to 120 µeq Na/L. Higher content of Cl and Na in soil solution suggested that sea salt significantly affect the soil solution chemistry in Fushan FDP. Moffat *et al.* (2002) also indicated that sea salt events are important at sites close to the coast, and influence chemistry for short periods. Calcium is the dominant cation in soil solutions of A and B horizons; hence the response to acidic anion or proton input would be through Ca mobilization in Fushan forest. Comparisons between Inceptisols and Ultisols showed that obviously lower content of cations and anions in B horizon in Ultisols, which suggest that the strong leaching effects occur.

Nutrient budget estimation

The amount of input was estimated from the element concentration and collection the quantity of throughfall, and the amount of output was evaluated including soil surface runoff and soil solution collected in the lowest layer of B horizon. Elemental inputs of K, Na, Mg, Cl, and SO₄ are obviously higher in the Ultisols area than those of the Inceptisols area (Table 1). The Ultisols are located at the northeastern side of the Fushan FDP receive more rainfall during the monsoon season in winter. In contrast, Inceptisols are located at the southwestern side and cannot handle as much rainfall. Robson *et al.* (1994) suggested that spatial variation greatly influence the chemical composition of throughfall, and the variations change with the characteristics of study area, such as stand and landscape position.

In the Inceptisols area, the budget of Si, Ca, and NO₃ has showed net loss, but K, Na, Cl, and SO₄ ions are net gain in soil. The other elements, including Mg, Fe, Al, and Mn, are almost balanced in soil. Only Si and

Ca have showed net loss, K, Na, Mg, Cl and SO₄ are net gain, and Fe, Al, Mn, and NO₃ are almost balanced in soil system of Ultisols. The introduction of strong mobile acid anion (SO₄²⁻) into these soil systems may enhance soil acidification via leaching of base cations from the exchange complex. Liu *et al.* (2008) investigated the soil solutions in three different horizons located on the upper slope, middle slope, and lower slope of a natural hardwood in Fushan forest from 2001 to 2004. Liu *et al.* (2008) also indicated that except for H⁺ when precipitation passed through the canopy, total ion concentration was increased, and concentrations of Na, K, Ca, Mg, F, Cl, PO₄³⁻, SO₄²⁻, and HCO₃⁻ in the throughfall generally exceeded the soil solution at the upper and middle slopes, whereas at the lower slope, Na, Ca, Mg, F, and Cl concentrations were highest at the 15 cm depth. This study has similar results to another study in Fushan FDP (Liu *et al.* 2008).



	Inceptisols		
	Inputs	Outputs	Inputs - Outputs
K	60.6	16.6	44.0
Na	54.6	20.9	33.8
Ca	22.4	81.8	-59.3
Mg	12.6	11.2	1.44
Fe	1.81	1.88	-0.07
Al	2.86	2.38	0.48
Mn	0.58	0.19	0.39
Si	4.84	7.51	-2.68
Cl	160	56.0	104
NO ₃	52.0	101	-49.2
SO ₄	99.3	49.5	49.8
	Ultisols		
	Inputs	Outputs	Inputs - Outputs
K	105	17.7	87.5
Na	62.6	19.6	43.0
Ca	24.4	51.3	-26.9
Mg	26.0	8.02	18.0
Fe	1.41	2.68	-1.27
Al	2.31	2.44	-0.13
Mn	0.69	0.13	0.6
Si	4.35	7.29	-2.94
Cl	231	62.2	169
NO ₃	40.6	40.5	0.03
SO ₄	127	54.6	72.2

Notes: The elements budget was calculated from the data collected from January 2008 to February 2009.

Uncertainty of nutrient budget estimation

In this study, the estimation of nutrient budget in the Fushan FDP was established and calculated based on evaluated database. For this reason, errors or uncertainties could occur, including (1) the limitation of sampling number and replication; (2) the difference of spatial distribution of soil properties and tree species; (3) the different nutrient concentration of tree species; (4) the estimation method of forest biomass and litterfall amount; (5) the lateral mobile of soil solution in soil layer; (6) the frequently effect and disturbance by typhoon; (7) the amount of increase from dry precipitation (input) and loss from evaporation (output); and (8) the overestimation of nutrient output based on the amount collected from the soil solution in B horizon.

Conclusion

The mean pH value of rain water and throughfall in the Fushan FDP during the study period is 4.6 and 4.7, respectively. The pH of soil solution has raised 1.5 pH units (pH 6.4 in average) after the throughfall percolation into the soils. Calcium is the dominant basic cation in soil solution, with a mean concentration of 341 $\mu\text{eq/L}$ and is much higher than in throughfall and surface runoff. The response to acidic anion or proton input would be through Ca mobilization in Fushan forest. The budget of Si, Ca, and NO_3 in the Inceptisol area and Si and Ca in the Ultisol area show a net loss. The input amount of K, Na, Cl and SO_4 are much higher than those of output, and suggest the net gain in soils. Iron, Al and Mn have similar input and output contents. In this study, the estimation and evaluation of nutrient budget based on throughfall, surface runoff, and soil solution (located in A and B horizon) seem that it is not sufficient and has many uncertainties factors. The long-term monitoring of precipitation inputs of nitrate and sulfate in the Fushan forest is important.

References

- Baeumler R, Zech W (1998) Soil solution chemistry and impact of forest thinning in mountain forests in the Bavarian Alps. *Forest Ecology and Management* **108**, 231-238.
- Berg B, Staaf H (1987) Release of nutrients from decomposing white birch leaves and Scots pine needle litter. *Pedobiologia* **30**, 55-63.
- Grimaldi C, Grimaldi M, Millet A, Bariac T, Boulegue J (2004) Behaviour of chemical solutes during a storm in a rainforested headwater catchment. *Hydrological Processes* **18**, 93-106.
- Hseu ZY, Chen ZS (1996) Saturation, reduction, and redox morphology of seasonally flooded Alfisols in Taiwan. *Soil Science Society of America Journal* **60**, 941-949.
- Hseu ZY, Chen ZS (2001) Quantifying soil hydromorphology of a rice-growing Ultisol toposequence in Taiwan. *Soil Science Society of America Journal* **65**, 270-278.
- Hseu ZY, Chen ZS, Leu IY (2000) Soil solution composition, water tables and redox potentials of anthraquic Ultisols in a toposequence. *Soil Science* **165**, 869-880.
- Liu CP, Lu SY, Wang CH, Hwang LS (2008) Soil solution chemistry on the three slopes of a natural hardwood stand in the subtropics of the Fushan forest. *Soil Science* **173**, 845-856.
- Moffat AJ, Kvaalen H, Solberg S, Clarke N (2002) Temporal trends in throughfall and soil water chemistry at three Norwegian forests, 1986-1997. *Forest Ecology and Management* **168**, 15-28.
- Robson AJ, Neal C, Ryland GP, Harrow M (1994) Spatial variations in throughfall chemistry at the small plot scale. *Journal of Hydrology* **158**, 107-122.
- Sposito G (1984) The future of an illusion-ion activities in soil solutions. *Soil Science Society of American Journal* **48**, 531-536.
- Su SH, Chang-Yang CH, Lu CL, Tsui CC, Lin TT, Lin CL, Chiou WL, Kuan LH, Chen ZS, Hsieh CF (2007) Fushan subtropical forest dynamics plot: tree species characteristics and distribution patterns. Taiwan Forest Research Institute (TFRI) Extension Series No. 177. 272 pp. (TFRI: Taipei, Taiwan).
- Tang CH, Yang CY (1976) Mid-tertiary stratigraphic break in the northeast Hsuehshan Range of Taiwan. *Petroleum Geology of Taiwan* **13**, 139-147.
- Tokuchi N, Takeda H, Iwatsubo G (1993) Vertical changes in soil solution chemistry in soil profiles under coniferous forest. *Geoderma* **59**, 57-73.
- Wu CC, Tsui CC, Hsieh CF, Asio VB, and Chen ZS (2007) Mineral nutrient status of tree species in relation to environmental factors in the subtropical rain forest of Taiwan. *Forest Ecology and Management* **239**, 92-101.

Store and release cover systems: A suitable preventive for acid mine drainage in semi-arid monsoonal Queensland?

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Abstract

Metalliferous mining operations are required to prevent contamination of the surrounding environment resulting from the discharge of leachates from waste repositories that may contain acid-forming sulfidic rocks or mine tailings. Waste rock cover systems are commonly used to isolate hazardous wastes from precipitation and thereby to prevent toxic or acidic mine drainage. Store and release cover systems are designed to retain all precipitated water within benign material overlying the waste, where the water is removed by evapotranspiration. Two cover designs were tested in semiarid monsoonal northwest Queensland: (1) 1.5 m of unconsolidated waste rock overlying 0.5 m of consolidated waste rock and (2) 2.0 m of unconsolidated benign waste rock. Cover performance was monitored with lysimeters, soil moisture and soil suction sensors. In a wet season with higher than usual precipitation (900 mm), water infiltration into underlying waste rock beneath bare covers varied from 3% to 76% of precipitation.

Key Words

Lysimeter, store and release cover, waste rock, drainage.

Introduction

Mining activities often result in the production of hazardous or potentially hazardous wastes such as waste rock from the mining operation and fine-grained wastes from minerals processing (tailings). Weathering of sulfidic waste rock in contact with water and oxygen can produce acid and metalliferous drainage and tailings often also contain a high levels of heavy metals or are sulfidic (Lottermoser 2007). Infiltration of precipitation into the waste material can result in the leaching of hazardous substances into adjacent environments. For mine lease relinquishment, mining companies are required to prevent any potential contamination of the surrounding landscape. In semi-arid environments, it is often proposed to use store and release cover systems (SRC) to enclose such hazardous wastes (Fourie and Tibbett 2007; Hauser *et al.* 2001). On mine sites, cover systems generally consist of benign (non-hazardous or non-acid-forming) waste rock which encapsulates waste rock dumps or tailings facilities. The thickness of the benign waste rock layer is designed according to site characteristics, climate (especially rainfall) and particle size distribution of the cover material. Other design features may include a compacted layer directly overlying the hazardous waste. The aim of a SRC system is to store precipitation in the benign waste rock and therefore prevent it from (deep) drainage and reacting with the hazardous waste. Stored rainwater is removed from the cover through evaporation and transpiration (O'Kane Consultants Inc. 2004). The theory of SRC systems is based on the water balance equation (Eq. 1)

$$L=P-Q-\Delta S-(EV+T) \quad (1)$$

Where L = seepage, P = precipitation, Q = runoff, ΔS = change in moisture content of the cover material, EV = evaporation and T = transpiration.

The objective of this paper is to investigate the feasibility of a bare SRC system for acid drainage prevention in a region with distinct wet and dry seasons in semi-arid monsoonal north-west Queensland, Australia.

Method

Field site

The mine site is located in a region classified as *BSh* (B = arid, S = steppe, h = hot arid) in the Köppen and Geiger Classification (Kottek *et al.* 2006). The mean monthly minimum and maximum temperatures are 11.6 and 37.3°C, respectively. The long-term annual rainfall of the area is 420 mm, but rainfall is highly erratic. Over 77 years of records, annual rainfall fluctuated between 104.9 mm in 1970 and 870.7 mm in 1950. Three-quarters of the annual precipitation occurs in the southern hemisphere summer, mainly between December and March but this is highly variable, from 78.0 mm in 1985/86 to 798.3 mm in 1996/1997, respectively. Most summer rainfall events are high intensity storms although the long-term data do not record these intensities (Bureau of Meteorology 2009a).

Cover trials

Two cover trial areas (20 m x 60m) were constructed in October 2008 with a supplemental installation of sensors in December 2008. The cover designs were: (1) 0.5 m compacted benign waste rock on the potentially acid-forming waste rock, overlaid by 1.5 m uncompacted benign waste rock (Treatment 1V) and (2) 2.0 m uncompacted benign waste rock placed directly on potentially acid-forming waste rock (2V). Each cover trial area was subdivided into three subplots (20 m x 20 m) and instrumented identically. In each subplot, a lysimeter (3 m diameter and 3 m deep) was placed into the hazardous waste material with its top being level with the surface of that material. Each lysimeter was connected to a tipping bucket gauge through a PVC pipe with a slope of ca. 2%. Furthermore, 16 soil matric potential sensors (229-L, Campbell Scientific, Logan UT USA) and 6 soil moisture sensors (Model CS616, Campbell Scientific, Logan UT USA) were installed in a single vertical line extending from the base of each lysimeter to the top of the cover system. A standard automatic weather station (Campbell Scientific, Logan UT USA) was mounted nearby.

Results

The data presented focuses on subplots 1Vb, 1Vc, 2Va and 2Vc based on integrity of the underlying data set.

Precipitation

The main period of precipitation in the wet season 2008/2009 began in the first week of December 2008 and ended in the second week of February 2009. No significant precipitation was received in March 2009. In total, 916 mm of rainfall was measured at the experimental site in an interval of 67 days. This rainfall was greater than that at the Bureau of Meteorology (BoM) station in the vicinity of the trials, which recorded 668mm of rainfall for the same period. The BoM rainfall for January 2009 was the highest and the 2008/2009 wet season was the third wettest since measurements commenced at the site in 1932 (Bureau of Meteorology 2009b).

Soil suction

The soil suction sensors responded quickly to rainfall events and the advance of the wetting front. The first major rain event on the 7th of December (27mm) triggered slightly different reactions on the subplots. Infiltration of rainfall proceeded approximately to the same depth on 2V (2Va: 1.02 m, 2Vc: 1.10 m) (Figure 1c, d). However, on Treatment 1V, infiltration was measured from 1.10 m (1Vc) to 1.99 m (1Vb), which indicates highly heterogeneous pore size distribution at this cover trial (Figure 1 a, b). The suction values clearly show that in all four subplots, rainfall infiltrated into the hazardous waste. On Treatment 1Vb this occurred after 151 mm cumulative rainfall (Figure 1a), whereas on Treatment 1Vc infiltration into the potentially acid-forming material first occurred after only 99 mm of cumulative rainfall (Figure 1b). On 2V, water reached the hazardous material after 108 mm and 140 mm cumulative rainfall in Treatments 2Vc and 2Va, respectively (Figure 1c, d). Beneficial influences of cover design, i.e. the compacted layer, on the hydrology of these cover systems cannot be claimed on the basis of the existing data.

Seepage

Seepage was recorded in all plots but the amount of seepage and time of occurrence varied between the subplots. No seepage was recorded from any plot between 13/01 and 24/01/2009. In these 10 days, a total of 253 mm of rainfall was recorded, with storm events of 37 mm, 48 mm and 50 mm on the 20th, 21st and 22nd of January, respectively. As the soil suction and soil moisture sensors were operating satisfactorily during this period, it is likely that tipping buckets were not functioning correctly during that time. Cumulative seepage rates range from 21 mm (2Va) up to 736 mm (1Vc) (Figure 2). Generally seepage from the covers with a 0.5 m compacted layer was higher than from the plots without a compaction zone. However the differences within the cover designs themselves are very pronounced. Approximately 310 mm more drainage was recorded at 1Vc compared with 1Vb, and at 2V the difference in drainage from the two lysimeters was almost 200 mm. From the four subplots under consideration, only 2Va showed drainage from the lysimeter of less than 5% of rainfall. The amount of water seeping out of the remaining three plots exceeded this acceptable threshold by a large margin.

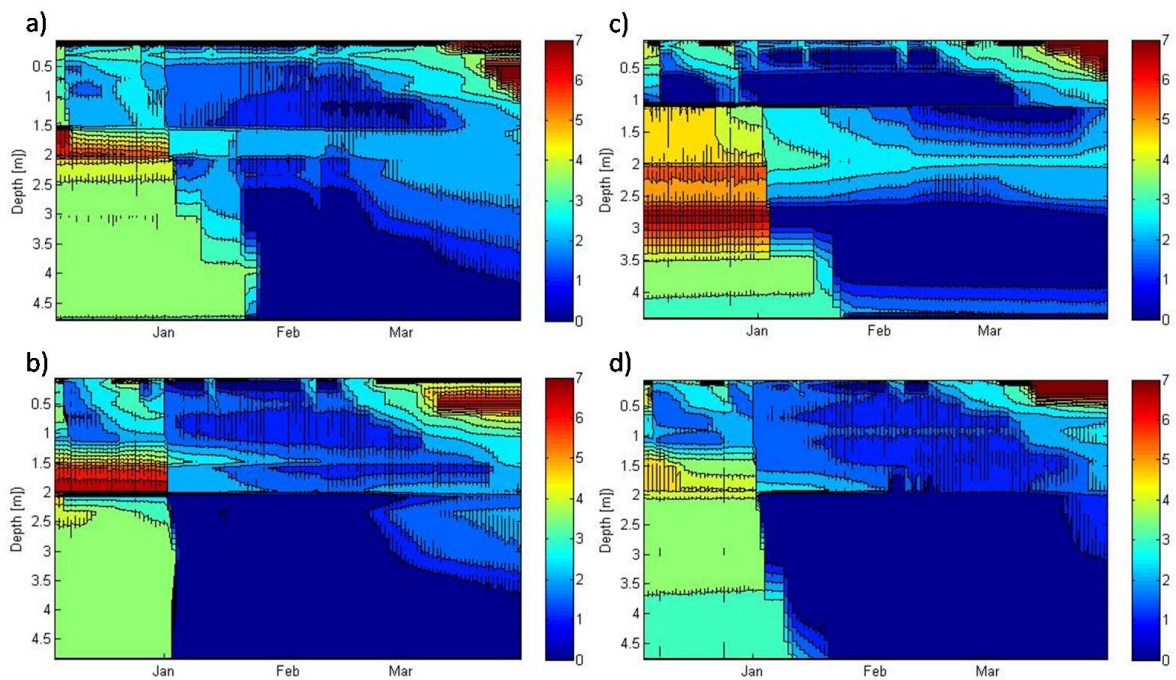


Figure 1. Logarithmic soil suction [hPa] over the course of the wet season 2008/2009 on subplots a) 1Vb, b) 1Vc, c) 2Va and d) 2Vc.

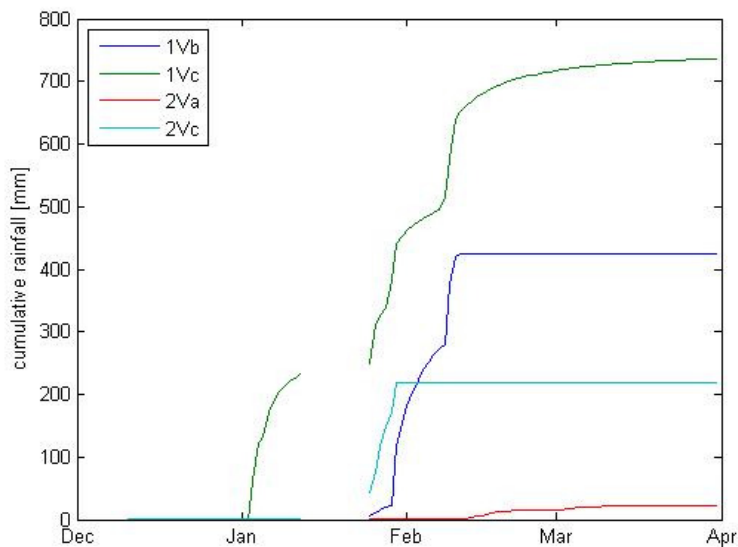


Figure 2. Cumulative seepage [mm] over the course of the wet season 2008/2009 on subplots 1Vb, 1Vc, 2Va and 2Vc.

Conclusion

In a wetter than normal wet season in north-west Queensland, seepage under a bare (non-vegetated) 2 m cover system can reach up to 76% of the 916 mm of rainfall received during the period under consideration. The importance of vegetation for the mitigation of seepage amounts has been stressed by several authors (Hauser *et al.* 2001; O'Kane Consultants Inc. 2004; O'Kane and Wels 2003). The presence of vegetation can enhance the storage capacity of a cover as more water is removed from the cover through evapotranspiration than by evaporation alone. However, the frequency and intensity of storm events in areas with distinct wet and dry seasons remain a challenge for SRC systems. If the rain patterns and extreme events of a region and the hydraulic properties of potential cover material are known, as well as the potential for the plant community to remove water from the cover, the maximal seepage rates through a cover can be estimated and a decision made on the suitability of a SRC for the region.

Reference

- Bureau of Meteorology (2009a) Climate Statistics Mount Isa Mine.
- Bureau of Meteorology (2009b) Monthly Rainfall Mount Isa Mine.
- Fourie AB, Tibbett M (2007) Post-Mining Landforms - Engineering a Biological System. In 'Mine Closure 2007 - Proceedings of the Second International Seminar on Mine Closure'. (Eds AB Fourie, M Tibbett, J Wiertz) (Santiago de Chile).
- Hauser VL, Weand BL, Gill MD (2001) Natural covers for landfills and buried waste. *Journal of Environmental Engineering-Asce* **127**, 768-775.
- Kottek M, Grieser J, Beck C, Rudolf B, Rubel F (2006) World Map of the Koeppen-Geiger climate classification updated. *Meteorologische Zeitschrift* **15**, 259-263.
- Lottermoser B (2007) 'Mine Wastes: Characterization, Treatment and Environmental Impacts.' (Springer: Berlin).
- O'Kane Consultants Inc. (2004) 'Design, Construction and Performance Monitoring of Cover Systems for Waste Rock and Tailings'.
- O'Kane M, Wels C (2003) Mine Waste Cover System Design - Linking Predicted Performance to Groundwater and Surface Impacts. In 'Proceedings of the 6th International Conference on Acid Rock Drainage' pp. 341 - 349 Cairns.

Studying water budget of paved urban sites using weighable lysimeter

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Abstract

Permeably paved surfaces make up a considerable percentage of total area in urban areas, especially in older cities. In urban hydrology one important task is keeping rain water in the unsaturated soil zone as long as possible in order to avoid floods and supply street trees with water. Our lysimeter study addresses a precise analysis of the water balance of two permeably paved surfaces. One surface is covered with concrete pavers and the second one with a so called "Bernburg mosaic of cobble stones". Both are typical for the sidewalks of Berlin. Using this instrumentation, actual evaporation, runoff and drainage can be studied with a high temporal resolution for various climate conditions. A typical runoff coefficient could be gained for a span of typical rainfall intensities. They are essential for developing new urban water management strategies. Furthermore, impact scenarios of expected climate change on urban heat stress and urban hydrology can be predicted.

Key Words

Permeable pavements, lysimetry, evaporation, run-off coefficients, water budget.

Introduction

Adaptation to climate change and mitigation of the urban heat island should include the development of sustainable management of water and especially rainwater in urban areas. Surface runoff should be avoided whenever possible. Infiltration is not possible everywhere (Goebel *et al.* 2007). Instead, water should be stored and evaporated, contributing to the reintegration of water and energy cycles and providing benefits from evaporation cooling. In this sense, paved soils play a key role as they cover great portions of urban areas. For instance in Berlin, 60% of the city centre is sealed (Senstadt-Berlin 2001), and 30% accounts for streets and sidewalks which are permeably paved. Here water can infiltrate through seams between single pavestones (Borgwardt 1993). Although it is reduced, permeable pavements generate run off. The proportion of run-off from rainfall (RC) varies with pavement design, infiltration capacity of the seams and of the ground (static RC) and with the rainfall intensity (dynamic RC) (Mansell and Rollet 2006; Rim 2009). Process based models for runoff and evaporation from paved soils are needed in order to describe (i) the conditions in existing urban areas and (ii) to assess the impact of climate change scenarios and adaptation strategies using simulations. Little is known on processes that influence the dynamic RC of pavements, especially on evaporation from paved urban soils. Weighable lysimeters are the method of choice to conduct process studies on water cycles. We introduce a study on paved lysimeters and present first results on dynamic RCs and evaporation.

Methods

The permeable surfaces take a considerable percentage in the whole urban area of Berlin. The joint space with seam material makes up the real path of infiltration and interception of the rainwater. It is exposed immediately to the environmental pollution. To achieve the reasonable boundary condition old joint materials from the different inner city sidewalks were obtained and used as seam material and bed for the lysimeter pavement. Each lysimeter had a surface in size of 1 m²; and a slope of about 2%. The lysimeter bodies stood in a 1.5 m deep cave on a scale with a 100g/sec resolution. The lysimeters were filled with construction sand to a depth of 1.3 m; there was a 0.2 m deep gravel layer on the ground. This served as a capillary blocking layer in the lower lysimeter boundary. The geotextile (polypropylene 1a white 500g) was placed around the gravel layer, serving as the leading capillary layer that captured the seepage water with four suction plates. The drainage could be measured with a resolution of 0.005g/sec. To measure the run-off separately, special gutters were set up directly along the surface edge that allowed the run-off to be immediately shunted to a separate discharge pipe where the run-off was measured in temporally high-resolution of 0.0005 mm/sec; no water was lost with this procedure.

The lysimeter wall and drain gutter are made of high-grade stainless steel. In the soil of lysimeter the water content and the soil temperatures will be measured by TDR sensors. The suction plates are set to a

subpressure of about -6.3 kPa. The paving coefficient of the cobble stone lysimeter is 45% and that of concrete paver is 7% (Rim 2009). Figure 1 illustrates the whole lysimeter construction which is found in Berlin Marienfelde, in the south of Berlin. Figure 2 and Figure 3 illustrate the individual aspects of the weighable lysimeter with Berlin's typical paving materials.

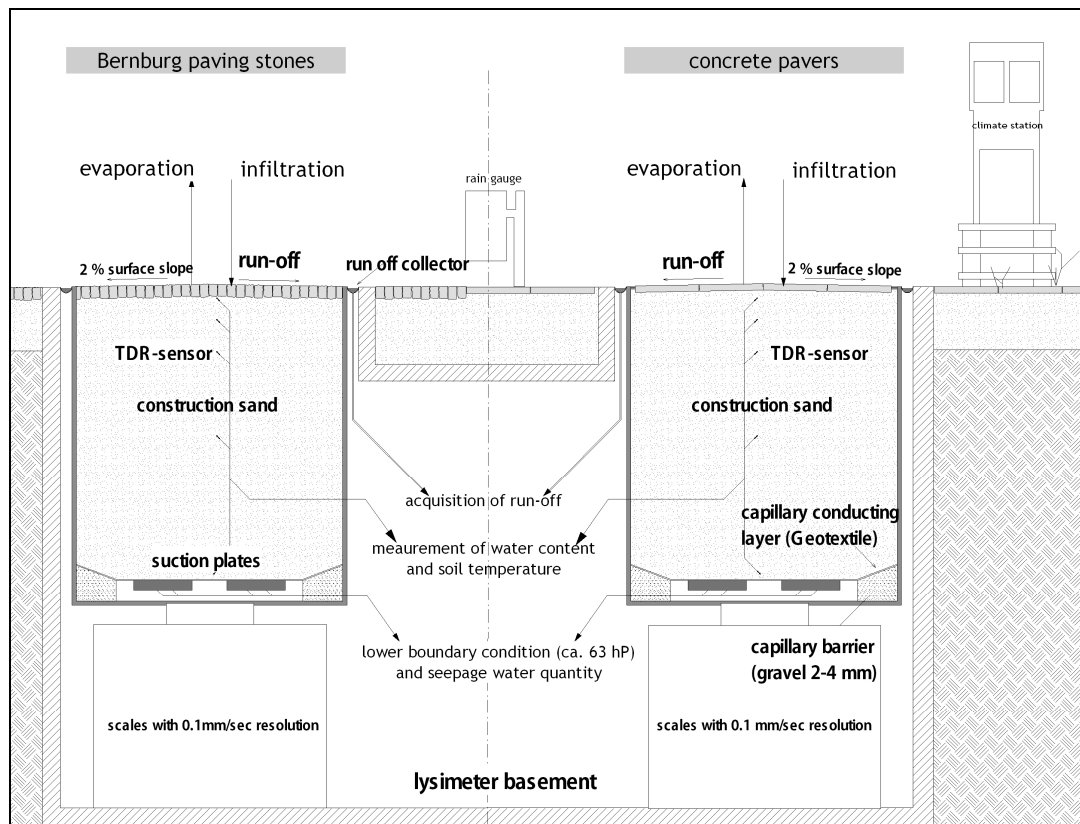


Figure 1. Construction of a weighable lysimeter system for studying the urban water budget.



Figure 2. Collection and measurement of run-off and groundwater recharge.



Figure 3. Views of lysimeter with cobble stones and concrete plates.

Results

Figure 4 shows the results of an irrigation experiment. It demonstrates how precisely rainfall could be measured using the weighable lysimeter. Results show a comparison to a Hellman rain gauge. Differences are $< 1\%$.

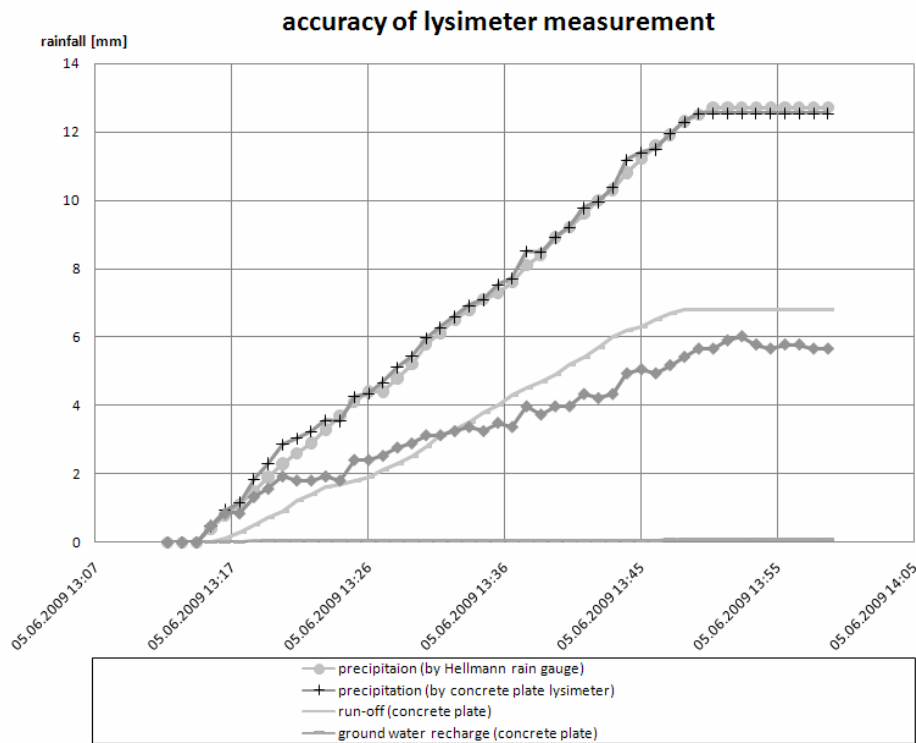


Figure 4. Accuracy of lysimeter measurement compared to data from rain gauge.

Run-off coefficients were dependent on the total rainfall, duration and intensity. Therefore, at first the whole precipitation continuum was separated into individual events of various intensities. The continuous rain data was grouped into individual distinctive events, each causing an individual distinctive run-off event. In most cases, the run-off process took longer than the rain event itself (dt in Figure 5), thus none of run-off event could be arbitrarily separated from the following rain event. The time span dt was set as the separation criterion. Figure 5 illustrates that a suitable separation coefficient of 10 min could be used to get individual run-off coefficients.

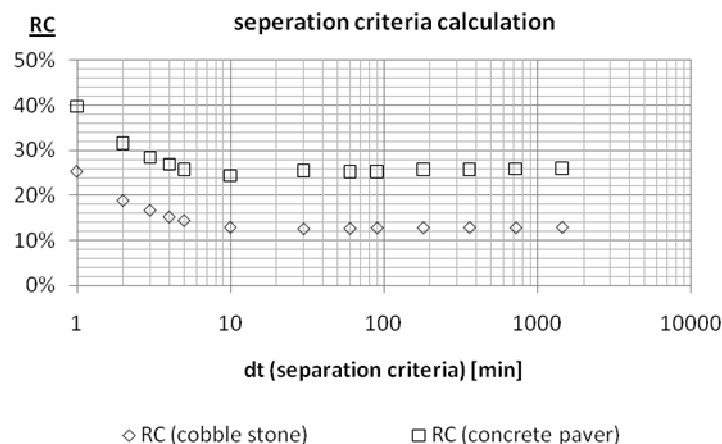


Figure 5. Criteria used for the separation of precipitation events.

About 160 rain events were separated and analyzed from April to September 2009. Rainfall events with intensities > 0.04 mm/min could produce runoff from cobble stone surface, while rainfall events with intensities > 0.02 mm/min could cause runoff from the concrete plate surface (Figure 5). After a rainfall intensity > 0.2 mm/min up to 0.5 mm/min, RCs for the concrete paver surfaces increased at a significantly

slower rate. RCs of cobble stone surface differed from concrete paver surfaces, continuing to increase even after intensities of >0.4 mm/min. These results lead to the conclusion that RCs are not dependent on the paving coefficient during strong precipitation events. These RC were typical for the rainfall characteristics of Berlin, Germany and should not be used for other climate regions without first adapting control variables.

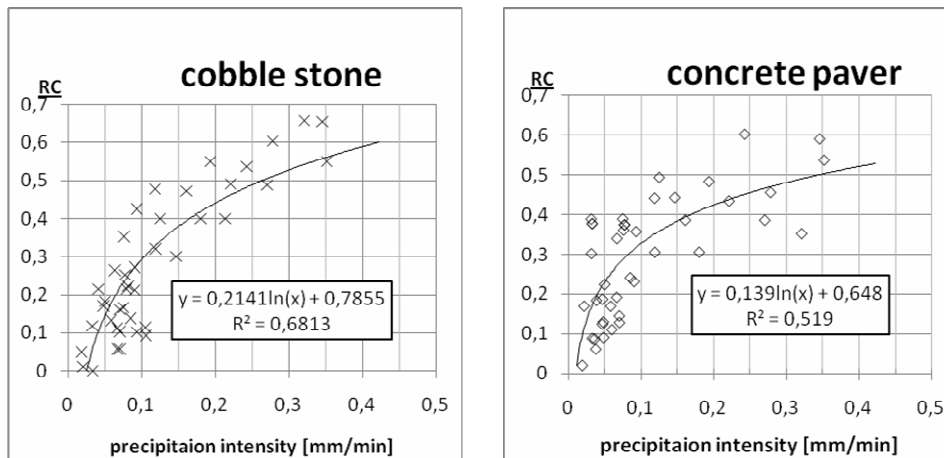


Figure 6. Runoff coefficient for cobble stone pavement (left) and concrete pavement (right)

References

- Göbel P, Dierkes C, Kories H, Meßer J, Meißner E, Coldewey WG (2007) Impacts of green roofs and rain water use on the water balance and ground water levels in urban areas. – *Z. Grundwasser* **12**,189-200.
- Flöter O (2006) Wasserhaushalt gepflasterter Strassen und Gehwege. Lysimeterversuche an drei Aufbauten unter praxisnahen Bedingungen unter Hamburger Klima. Dissertation, Hamburger Bodenkundliche Arbeiten, ISSN: 0724-6382, 329.
- Mansell MG, Rollet F (2007) The Water Balance of Paved Surfaces in Urban Areas. In ‘Proc. SUDSnet National Conf. Nov 2007’ (Coventry).
- Rim Y, Nehls T, Trinks S, Wessolek G (2009) Eine teilversiegelte Lysimeteranlage in Berlin. In ‚LFZ Raumberg-Gumpenstein, Tagungsband der 13. Gumpensteiner Lysimetertagung’ ISBN: 978-3-902559-31-9.
- Wessolek G, Facklam M (1999) Aspekte zur Wasserbilanz versiegelter Standorte. In ‘Regenwasserversickerung und Bodenschutz’ (Eds W Burghardt, B Mohs, G Winzig) pp. 50-55 (Erich Schmidt: Regensburg).

The effect of rye green manure application with nitrogen fertilizer on soil water storage, soil aggregate stability and soil water infiltration rate in Maragheh dryland condition

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Abstract

With the aim of green manure application improving soil physical characteristics important to soil water retention in dry land condition, this study was carried out with or without rye green manure along with 4 nitrogen fertilization treatments (0, 26, 103 and 337 (kg N/ha) in 3 rotation system (green manure-wheat) between 2001 – 2007 years. Results showed that the green manure application effects were significant for soil aggregate stability. Results showed that the green manure application effects were significant on the soil bulk density and soil moisture indexes such as FC and PWP. N-fertilizer application with green manure in order to decrease C/N ratio for best activation of soil microorganisms accelerated these effects. High AWC occurred for C/N=20 treatment. Our data showed that there are regression relationships with highly correlation coefficients between the levels of N-application with green manure and soil moisture indexes. Our results also showed that green manure application had a significant effect on soil water infiltration rate for dry land condition. Higher and lower infiltration rates occurred for C/N=36 and C/N=20 treatments respectively at 30 min. A soil water infiltration prediction Kostiakov model was determined as a best model for its higher R square ($R^2 = 0.90$) and lower standard error (SE=0.30). The model predicted about 90 % of variation in soil water infiltration rate for all of the treatments in this study.

Key Words

Soil water content, green manure, aggregate stability, dry land condition.

Introduction

Crop production in dryland conditions depends on rainfall as in this region rainfall is limited and seasonal (Farahani 1998; Sandhu *et al.* 1992). Thus increasing soil water storage ability and water conservation in such regions could be one of the most important agricultural management practices (Mosavi *et al.* 2009). For this purpose it is necessary that we improve soil structure and facilitate water infiltration to soil to increase water utilization (Martens and Franken 1992). It was reported that organic matter has a key role in aggregate formation and structure stability in soil (Pikul *et al.* 2005, Annabi *et al.* 2007). Movement of water into the soil is controlled by gravity, capillary action, and soil porosity. Of these factors soil porosity is most important (Martens *et al.* 1992). Soil porosity is controlled by its texture, structure, and organic content (Martens *et al.* 1992). The amount of decayed organic matter found at the soil surface can also enhance infiltration. Organic matter is generally more porous than mineral soil particles and can hold much greater quantities of water (Annabi *et al.* 2007). The general objective of the work presented here was to determine the effect of rye green manure in rotation with wheat on the soil moisture content, aggregate stability and water infiltration rate for dry land conditions.

Materials and methods

The study was conducted at a research station of the dryland agriculture research institute in Maragheh. The soil of the field experiment is a clay loam (Fine Mixed Active, Mesic Typic Calcixercept). Winter type rye (*Secale cereale*) was cultivated in autumn and in spring rye green residues was added to soil along with nitrogen: 0, 26, 103 and 337 kg N/ha from urea fertilizer plus check (without green manure) treatment. This level of N was added synchronous with rye residue additional to soil. This study was carried out in 3 rotation system (green manure –wheat) in PCBD design with 4 blocks at 2001 – 2007. Soil water indexes such as saturation percentage (SP%), field capacity (FC), permanent wilting point (PWP) and 30 cm water column were measured by undisturbed sampling from the field experiment in each treatment at two deptsh (0-5 cm and 10-20 cm) using a pressure plate method and also bulk density was measured in this sample using a cylinder method (Margeson and Schinner 2005). Soil aggregate stability was measured using the Kemper and

Rosenau (1986) method. The 1-2 mm particle size and soil infiltration rate were measured in each treatment in field condition using a double ring cylinder method. Statistical analyses were done using Genstat Software (version 9.00, 1995).

Result and discussion

Analysis of variance for different important weight moisture indexes such as SP, FC, PWP, 30cm water column and AWC showed that the block effect was not significant for these indexes. Treatment effects was significant on the PWP ($P < 5\%$) and FC ($P < 1\%$) whereas was not significant for the other investigated moisture indexes. Depth effect was not significant on the FC, PWP and AWC but was significant on the SP and 30cm water column at $P < 0.01$ level. Treatment \times Depth effects were not significant for any of the factors that were investigated in this research. Investigation of regression relationships between different N-levels application with green manure showed that a highly correlation coefficient exists among for green manure application and different levels of N use with important soil moisture indexes (data not shown). Our data showed that soil bulk density decreased when green manure applied in rotation with wheat cultivation and nitrogen application, with rye green manure accelerating this effect. Lower bulk density occurred for C/N=20 and highly bulk density for the Control. This trend was not significant between different treatments of this study (Table 1). Our results show that green manure application affected the important soil moisture indexes and increased the soils ability to hold water because organic matter has a higher water holding capacity than a similar volume of mineral soil (Annabi *et al.* 2007). Soil organic matter enhances soil water retention because of its hydrophilic nature and its positive influence on soil structure (Annabi *et al.* 2007). Data for water infiltration into soil showed that between the experimental treatments the highest amount of cumulative infiltration was for green manure application without nitrogen that had a 9% increase with respect to control (Table 4). The high infiltration rate of 46.8 mm/hr over 5 minutes occurred for C/N=30 but after 30 minutes the highest level was for C/N=36 (20.4 mm/hr) (Table 4). Our data were examined with three prediction models for soil water infiltration (Green – Ampt, Kostiakov and Kostiakov – Lewis) and showed that the adjusted Kostiakov model was the best model based on its higher R square ($R^2 = 0.90$) and lower standard error (SE=0.30). The model predicts about 90 % of variation in soil water infiltration rate for all of the treatments in this study (Table 5). Aggregate stability measurements for 1-2 mm particles showed that there are significant differences between green manure treatments ($p < 0.05$). Lowest stability was for C/N=30 treatment and was lower than for control. Stability was not significantly different between C/N= 10, 20 and 30 treatments and was higher than control. These results showed that green manure application has a improves aggregate stability and it seems that the C/N ratio has a determinant role in aggregate stability and some ratio stability decreased.

Table 1. Variance analysis for effects of green manure treatments on soil moisture indexes.

MS							
S.O.V	df	Db(gr/cm^3)	Pm(30cm)	Pm(FC)	Pm(PWP)	Pm(SP)	Pm (aw)%
Replication	3	0.00706 ns	27.42 ns	9.252 ns	18.541 ns	72.64 ns	20.597 ns
Treatment	4	0.00796 ns	9.18 ns	6.727**	22.411*	49.63 ns	13.711 ns
Depth	1	0.93128**	218.76**	0.706	6.174	5651.28**	2.703
Treatment*Depth	4	0.00446ns	3.95 ns	0.919 ns	5.193 ns	19.91 ns	4.756 ns
Residual	27	0.01031	15.11	1.225	8.063	48.92	6.673
C.V%		10.2	9	3.4	11.2	11.1	35.6

Table 2. Comparison of mean values for green manure treatment effects on soil moisture indexes.

Treatment	Db(gr/cm^3)	Pm(30cm)	Pm(FC)	Pm(PWP)	Pm(SP)	Pm (aw)
Check	1.021	42.97	33.71	28.13	60.5	5.58
36=C/N	1.031	42.14	31.47	25.12	60.5	6.35
C/N=30	1.007	44.66	33.03	25.18	63.2	7.86
C/N=20	0.952	44.43	32.82	23.91	66.3	8.91
C/N=10	0.984	42.95	31.8	24.19	64.2	7.61
LSD5%	0.1042	3.988	1.135	2.913	7.18	2.65

Table 3. Comparison of means for soil depth effects on soil moisture indexes.

Depth	Db(gr/cm^3)	Pm(30cm)	Pm(FC)	Pm(PWP)	Pm(SP)	Pm (aw)%
5cm	0.846	45.77	32.7	25.7	74.8	7
15cm	1.152	41.09	32.43	24.91	51	7.52
LDS%	0.0659	2.522	0.718	1.842	4.54	1.676

Table 4. Mean cumulative and infiltration rate for different treatment in four different times.

Treatment	Time (min)							
	5		10		15		30	
	Cumulative mm	Infiltration rate mm/min	Cumulative mm	Infiltration rate mm/min	Cumulative mm	Infiltration rate mm/min	Cumulative mm	Infiltration rate mm/min
Check	7.7	0.56	12.3	0.46	18.5	0.38	29.3	0.27
C/N=36	6.8	0.4	10.8	0.4	16.6	0.39	28.5	0.34
C/N=30	11.2	0.78	15.6	0.44	20.8	0.28	28.4	0.21
C/N=20	9.7	0.44	12.5	0.28	17.5	0.28	25	0.2
C/N=10	7.1	0.5	11.9	0.48	17.9	0.37	28.4	0.31

Table 5. Comparison of three different equations coefficients for infiltration rate data.

Treatment	Green - Ampt				Kastiakov				Kastiakov - Lewise				
	k	b	SE	R ²	a	b	SE	R ²	a	b	c	SE	R ²
Check	-0.306	3.029	0.19	0.87**	4.709	0.326	0.193	0.86*	117.893	0.011	0.234	0.158	0.93**
C/N = 36	0.151	1.148	0.182	0.74ns	2.044	0.552	0.147	0.83*	3.094	0.307	0.213	0.157	0.85*
C/N = 30	-0.612	6.099	0.157	0.96**	7.637	0.278	0.126	0.97**	14.532	0.138	0.141	0.133	0.98**
C/N = 20	-6.016	43.213	1.086	0.63ns	186.75	0.019	0.794	0.80*	170.596	0.025	-0.413	0.803	0.84*
C/N = 10	-0.69	4.694	0.307	0.78*	40.818	0.0446	0.261	0.84*	240.125	0.007	0.154	0.254	0.88**

Reference

- Annabi m, Houot S, Francou C, Poitrenaud M, Bissonnais YL (2007) Soil aggregate stability improvement with urban composts of different maturities. *Soil Sci. Soc. Am. J.* SSSAJ **71**, 413-423
- Bowman RA, Vigil MF, Nielsen DC, Anderson RL (1999) Soil organic matter changes in intensively cropped dryland systems. *Soil Science Society of America journal J.* **63**, , 186-191.
- Farahani H J (1998) Soil water storage in dryland cropping systems: the significance of cropping intensification. *Soil Sci. Soc. Am. J.* Soil Sci Soc Am J **62**, 984-991.
- Kemper WD, Rosenau RC (1986) Aggregate stability and size 'Methods of soil analysis. Part 1. Physical and mineralogical methods'. (Ed A Klute) distribution In : Klute A., Methods of soil analysis , part 1. (American Society of Agronomy Inc.: Madison, WI). Agronomy monograph s, 9. American society of agronomy, Mdison WI.
- Margesin R, Schinner F (2005) 'Manual for Soil Analysis – Monitoring and Assessing Soil Bioremediation'. (Springer-: Verlag Berlin Heidelberg). 370 pages.
- Martens DA, Frankenberger WT(1992) Modification of infiltration rates in an organic-amended irrigated *Agron J.* **84**,707-717
- Mosavi SB, Jafarzadeh AA, Neishabouri MR, Ostan SH (2009) Application of rye green manure in wheat rotation system alters soil water content and chemical characteristics under dryland condition in Maragheh. *Pakistan Journal of Biological Science* **12**, 178-182.
- Pikul J, Johnson J, Wright J, Caesar S, Ellsbury T, Michael (2005) 'Soil organic matter and aggregate stability affected by tillage'. March 1 conference., (Taylor and Francis, Inc.: New York. p. 243-258.).
- Sandhu KS, Benbi DK, Prihar SS, , Saggat S (1992) Dry land wheat yield dependence on rainfall, applied N and mulching in preceding maize. *Nutrient Cycling in Agroecosystems* **32**, 229-237.

The partitioning of evapotranspiration of irrigated wheat as affected by rice straw mulch

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Abstract

Soil evaporation is considered to be a non productive component of evapotranspiration (ET). Measures which moderate soil evaporation may influence the amount of water available for transpiration, the productive component of ET. Field experiments investigating the effect of rice straw mulch on components of the water balance of irrigated wheat were conducted during 2006-07 and 2007-08 in Punjab, India, on a silt loam soil. Daily soil evaporation (Es) was measured using mini-lysimeters, and total seasonal evapotranspiration (ET) was estimated from the water balance equation using measurements of irrigation, rainfall and soil water depletion. The mulch lowered total soil evaporation over the crop growth season by 35 and 40 mm in relatively high and low rainfall years, respectively. Much of this “saved water” was partitioned into transpiration, which increased by 30 and 36 mm in the high and low rainfall years, respectively. As a result, ET was not affected by mulching in either year. This is a very important finding in relation to the potential for mulching to save water and increase WP_{ET} . In both years, there was significantly higher tiller survival and grain weight with mulching, and this led to significantly higher grain and total biomass yields in 2006-07, probably because the non-mulched treatment suffered from water deficit stress for a period after maximum tillering that year. Transpiration water productivity with respect to grain yield was 18.8-19.1 kg/ha/mm in 2006-07, and 14.6-16.1 kg/ha/mm in 2007-08. There was trend for mulch to lower transpiration water productivity, significantly in 2007-08. The results suggest that while mulching of well-irrigated wheat reduces soil evaporation, it does not “save” water because the crop compensates by reduced transpiration efficiency.

Key Words

Soil evaporation, transpiration efficiency, north-west India

Introduction

In the intensive irrigated rice-wheat (RW) systems of Punjab, India, wheat occupies 3.5 Mha, of which 2.6 Mha follows immediately after rice. Rice residues are normally burnt prior to wheat sowing, creating severe air pollution and loss of nutrients. Recent machinery developments enable simultaneous mulching of rice residues as well as the direct drilling of wheat in to these residues (Sidhu *et al.* 2007). The presence of rice residues on the soil surface may produce benefits such as reduction in soil evaporation. Soil evaporation (Es) is considered to be a non-beneficial loss of water, aside from its effects of moderating air and canopy temperature and humidifying the air (Leuning *et al.* 1994). Mulching offers the potential to reduce soil evaporation by the interception of solar radiation and reduction of wind speed close to the soil surface. In semi arid regions, the Es component of total seasonal evapotranspiration (ET) of annual crops accounts for 30 to 70% of ET (Zhang *et al.* 1998), and is important in irrigated cropping systems like the irrigated RW systems in north-west India where the soil is frequently subjected to wetting and drying cycles. Therefore, measures which offers the potential to reduce soil evaporation such as mulching are of interest for their potential to reduce water loss and increase water productivity.

Several recent studies in north-west India showed that soil water content was higher under wheat mulched with rice straw than without mulch (Sidhu *et al.* 2007; Yadvinder-Singh *et al.* 2008), but in these studies no attempt was made to quantify the effect of the mulch on ET, or to partition this into effects on Es and transpiration (T). Decreasing Es may lead to increased T as a result of both higher vapour pressure deficit and by preserving more water for T in water limited environments (Eberbach and Pala 2005) and result in more yield as a result of the linear relationship between T and biomass production as suggested by Passioura (1977). Therefore, in calculations of water use efficiency and in modelling studies, it is necessary to measure and simulate Es and T separately and accurately.

Several approaches have been used to separate the Es and T components of ET. Direct measurement of Es has been made successfully using mini lysimeters placed between rows (Allen 1990). In the present study, we measured Es for the whole season using mini lysimeters to study the effect of mulch on the partitioning of ET in irrigated wheat in Punjab, India. Our hypothesis was that mulching would reduce soil evaporation, with the amount offset conserved for transpiration.

Methods

Field experiments were conducted in 2006-07 and 2007-08 at the Punjab Agricultural University farm at Ludhiana (30°56'N, 75° 52'E, 247m ASL), Punjab, India, on a silty loam soil. Two residue management treatments (mulch, non-mulch) were implemented in 12 m x 6 m plots with 4 replicates in a random block design. The preceding rice crop at the experimental site was harvested by combine harvester in mid-October each year, leaving standing straw (20-25 cm) and loose residues (total residues 8.3 t/ha). Rice straw was removed mechanically from the non-mulch plots, leaving stubbles about 2-3 cm high. Wheat (var. PBW343) was sown (100 kg/ha) using the Combo Happy Seeder (Sidhu *et al.* 2007) on 6th November 2006 and 13th November 2007 and grown using recommended practices. Nitrogen (60 kg N/ha: 50 kg N/ha as urea and 10 kg/ha as diammonium phosphate) and 26 kg P/ha (as diammonium phosphate), were banded with the seed, and a further 60 kg N/ha was applied as urea broadcast, at the time of crown root initiation (before the first irrigation after sowing). Weeds were controlled chemically by spraying Leader (Sulfosulfuron) @ 32.5g/ha and 2, 4-D @ 625g/ha after the first irrigation. After that, irrigations were scheduled using the ratio $I:(CPE - \text{rain}) = 0.9$ where I is the irrigation amount (75 mm for all irrigations) and CPE is net cumulative pan evaporation since the last irrigation. Irrigation volume was measured with a Wolman helical turbine meter.

Volumetric soil water content (SWC) was determined to a depth of 180 cm at sowing and harvest from gravimetric SWC and bulk density. In addition, neutron counts were made to a depth of 165 cm approximately twice weekly, and immediately before each irrigation, in all 4 replicates, using a CPN 2007 neutron moisture meter. The neutron moisture meter was calibrated for each soil layer separately over a range of values of SWC.

Soil evaporation below the wheat canopy was measured directly using mini-lysimeters which were weighed manually daily (at 24 h intervals). The mini-lysimeters consisted of open PVC cylinders 20 cm deep, 10 cm outside diameter, installed mid-way between the crop rows. After 5 days, fresh soil cores were installed in the lysimeters.

Evapotranspiration (mm) was estimated using a standard water balance equation: $ET = dSWC + P + I - D - R$, where dSWC is the change in soil water content (0-180 cm) between consecutive neutron probe readings, P is precipitation, I is the amount of irrigation and D is the drainage beyond 180 cm. Drainage was assumed to be negligible as tensiometers installed at 120, 140, 160 and 180 cm suggested no water movement beyond 120 cm (there was no change in soil matric potential at any of these depths following irrigation or rain). There was no runoff ($R=0$) from the plots.

Results and discussion

Total rainfall during the 2006-07 wheat season was 159 mm and was well distributed, so there was only one post-sowing irrigation. The 2007-08 season was generally dry, with total growing season rainfall of 88 mm received late in the season, and three post sowing irrigations were applied. Total crop ET was not affected by mulching, and was 341-345 and 400-404 mm in 2006-07 and 2007-08, respectively (Table 1). Cumulative Es in the non-mulched crop was 135 and 162 mm in 2006-07 and 2007-08, respectively, which is equivalent to 39 and 40% of ET each season. With mulch, calculated cumulative Es was reduced significantly to 100 and 121 mm, equivalent to 29 and 30% of ET in respective years. Transpiration was significantly higher with mulch in each year. During the early part of the crop growth season when LAI was low (up to 40-45 days after sowing), Es was the major part of ET (Figure 1). During this period, soil water content (0-15 cm) in the mulched wheat was significantly higher than without mulch and ensured more water for transpiration later in the season.

There was a trend for higher grain yield and total biomass with mulching, and the differences were significant in 2006-07 (Table 1). This was due to significantly higher spike density and grain weight, the benefits of which were offset by significantly fewer grains per spike each year (data not presented). The

lower spike density without mulch was associated with higher tiller mortality, especially in 2006-07. The reason for the high tiller mortality without mulching in 2006-07 is probably due to soil water deficit stress for about 10 days after maximum tillering, as evidenced by tensiometer data (not presented). If so, this would suggest that an IW/(CPE-rain) ratio of 0.9 is sub-optimal in some seasons. Each year, post-anthesis biomass accumulation was greater in the mulched treatments, and post-anthesis transpiration was significantly higher in the mulched treatment. This is consistent with the findings of others that transpiration is directly linked with crop biomass production (Passioura, 1977). The higher grain yield with mulching in 2006-07 is consistent with the finding that 70-90% of grain yield is from post anthesis photosynthesis (Bidinger *et al.*, 1977).

Table 1. Soil water balance components and transpiration efficiency under mulch and non mulched wheat during 2006-07 and 2007-08.

	2006-07			2007-08		
	Mulch	Non-Mulch	L.S.D (0.05)	Mulch	Non-Mulch	L.S.D (0.05)
Irrigation (mm)	75	75	-	225	225	-
Rain (mm)	159	159	-	88	88	-
dSWC (mm)	-107	-111	NS	-87	-91	NS
ET (mm)	341	345	NS	400	404	NS
Soil evaporation (mm)	101	135	10	121	161	17
Transpiration (mm)	240	210	26	279	242	29
Grain yield (t/ha)	4.5	4.0	0.2	4.1	4.0	NS
Total biomass (t/ha)	10.6	9.2	0.7	10.2	10.0	NS
Grain transpiration efficiency (kg grain/mm/ha)	18.8	19.1	NS	14.6	16.4	1.2
Total biomass transpiration efficiency (kg/mm/ha)	43.9	43.8	NS	36.6	41.4	3.1

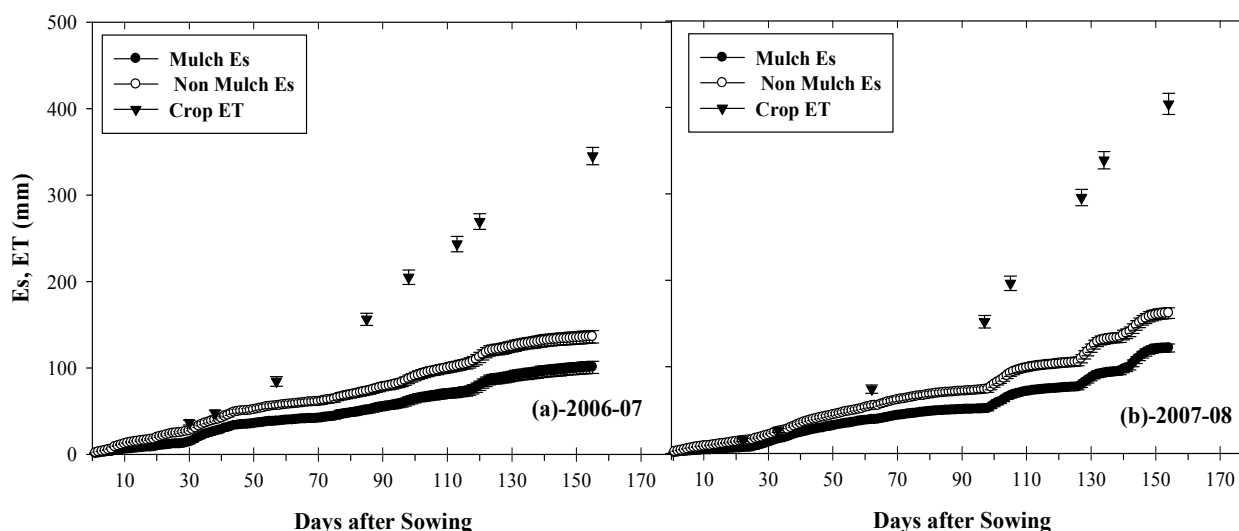


Figure 1. Cumulative soil evaporation (Es) and evapotranspiration (ET) with and without mulch during (a) 2006-07 (b) 2007-08.

There was a consistent trend for lower grain and total biomass transpiration efficiency with mulching, and the differences were significant in 2007-08 (Table 1). Grain transpiration efficiency was close to values observed for wheat elsewhere (Zhang *et al.* 1998). The lower transpiration efficiency with mulch may result from a low ratio of photosynthesis to transpiration at the leaf level under conditions of high water availability. Chakraborty *et al.* (2008) observed continuous low canopy temperature under mulch, and suggested that this was because the stomata remained open for longer periods, leading to higher transpiration and thus a lower photosynthesis/transpiration ratio.

Conclusions

Mulching suppressed soil evaporation by 35–40 mm and increased transpiration by a similar amount between anthesis and maturity of irrigated wheat. This was true in both a year of well-distributed rain (one post sowing irrigation only), and in a relatively dry year when 3 irrigations were required. As a result, water loss as ET was not affected by mulching in either year. This is a very important finding in relation to the potential for mulching to save water and increase WP_{ET} , and warrants further investigation.

Mulching reduced tiller mortality and increased post-anthesis biomass production in both years, and this resulted in significantly higher grain and biomass yields in the higher rainfall year. This, together with soil matric potential observations, suggests that the non-mulched treatment may have suffered from water deficit stress during that year, and that an $I/(CPE\text{-rain})$ ratio of 0.9 may be suboptimal in some seasons.

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References

- Allen SJ (1990) Measurement and estimation of evaporation from soil under sparse barley crops in northern Syria. *Agricultural and Forest Meteorology* **49**, 291-309.
- Bidinger F, Musgrave RB, Fischer RA (1977) Contribution of stored pre-anthesis assimilate to grain-yield in wheat and barley. *Nature* **270**, 431-433.
- Chakraborty DN, Aggarwal S, Gupta P, Tomar VK, Garg RK, Sahoo RN, Sarkar RN, Chopra A, K.Sarma U, Kalra, KSSN (2008) Effect of mulching on soil and plant water status, and the growth and yield of wheat (*Triticum aestivum* L.) in a semi-arid environment. *Agricultural Water Management* **95**, 1323-1334.
- Eberbach PL, Pala M (2005) Crop row spacing and its influence on the partitioning of evapotranspiration by winter-grown wheat in Northern Syria. *Plant and Soil* **268**, 195-208
- Leuning R, Condon AG, Dunin FX, Zegelin S, Denmead OT (1994) Rainfall interception and evaporation from soil below a wheat canopy. *Agricultural and Forest Meteorology* **67**, 221-238.
- Passioura JB (1977) grain-yield, harvest index, and water-use of wheat. *Journal of the Australian Institute of Agricultural Science* **43**, 117-120.
- Siddique KHM, Tennant D, Perry MW, Belford RK (1990) Water use and water use efficiency of old and modern wheat cultivars in a Mediterranean-type environment. *Australian Journal of Agricultural Research* **41**, 431-447.
- Sidhu HS, Manpreet-Singh, Humphreys E, Yadvinder-Singh, Balwinder-Singh, Dhillon SS, Blackwell J., Bector V, Malkeet-Singh, Sarbjeet-Singh (2007) The Happy Seeder enables direct drilling of wheat into rice stubble. *Australian Journal of Experimental Agriculture* **47**, 844-854.
- Yadvinder-Singh, Sidhu HS, Manpreet-Singh, Humphreys E, Kukal SS, Brar NK (2008) Straw mulch, irrigation water and fertiliser N management effects on yield, water use and N use efficiency of wheat sown after rice. In 'Permanent beds and rice-residue management for rice-wheat systems in the Indo-Gangetic Plain'. (Eds Humphreys E, Roth CH). Proceedings of a workshop held in Ludhiana, India, 7-9 September 2006. ACIAR Proceedings No. 127. Australian Centre for International Agricultural Research (Canberra, Australia), pp. 171-181. <http://www.aciar.gov.au/publication/term/18>.
- Zhang H, Oweis TY, Garabet S, Pala M (1998) Water-use efficiency and transpiration efficiency of wheat under rain-fed conditions and supplemental irrigation in a Mediterranean-type environment. *Plant and Soil* **201**, 295-305.