Performance of geotextile-gravel bed all-weather surfaces for cattle

H. von Wachenfelt [a,*]

[a] Department of Rural Buildings, Swedish University of Agricultural Sciences, P.O. Box 86, SE 230 53 Alnarp, Sweden. *E-mail corresponding author: Hans.von.Wachenfelt@slu.se

Abstract

A cost-effective way of producing all-weather surfaces for cattle is to use a combined geotextile-gravel pad construction, which allows pavement depth to be reduced. This study sought to determine the pavement construction that would offer the least runoff, best drainage effect and highest quality runoff and drainage effluent after exposure to heavy precipitation under different manure loads in high animal density areas. The study also examined whether any pavement construction gave acceptable sealing to the underlying soil surface.

Three different combinations of non-woven and woven geotextile together with two gravel fractions of 200 mm were exposed to 50 mm precipitation for 30 minutes and 15 kg of cattle manure under two manure regimes (manure removal and manure accumulation). Runoff, drainage effluent and leachate were flow measured and sampled in buckets as they exited their respective pipes for both regimes.

The pad surface layer reduced runoff flow rate and stabilised drain flow throughout the experiments, confirming pad stability. Manure removal reduced total N, total P, chemical oxygen demand (COD) and total solid (TS) concentrations in drainage effluent. One pad construction proved better at oxidising NO_2-N and another at trapping TS. One pad construction met the sealing liner norm to the underlying soil. The drainage effluent produced was acceptable for wetland treatment. The results show that geotextile and gravel pad constructions not only have a supporting and draining function, but also a filtering, aerating and sealing effect.

Keywords: outdoor areas, geotextile, cattle, manure, runoff, drain, leachate.

1. Introduction

1.1 Background

Animals have a need for outdoor exercise even during the winter season (Gustafson 1993; Regula, Danuser, Spycher, & Wechsler, 2004). To stay in good physical condition, cattle should walk at least 3-4 km per day (Phillips, 2002). Outdoor transport areas and yards close to barns are often muddy because of high animal densities. Muddy walkways decrease animal traffic and can lead to malnutrition, and can also impede farm equipment transportation (Riskowski & DeShazer, 1976; Degen & Young, 1993; von Wachenfelt, 1998; Gunnarsson et al., 2003). The major problem is poor pavement construction combined with high water content in soil material and high animal density.

Many improvements in pavement construction have been made to provide all-weather surfaces for cattle, such as drained gravel pads, or concrete and asphalt as solid, non-permeable areas. These construction measures are expensive and promote runoff compared with permeable surfaces (White, 1973).

1.2 Agriculture source of non-point pollution

Research findings indicate that the ultimate driver of eutrophication in agricultural landscapes is the phosphorus (P) flowing into the watershed as a result of the use of fertilisers and animal feed (Reed-Andersen, Carpenter, & Lathrop, 2000). Söndergaard, Jensen, and Jeppesen (2005) showed that internal loading of P can delay lake recovery for many years after P loading reductions.

Manure and urine patches on wet soil during grazing can be a source of surface water and groundwater pollution, especially on sandy soils (Chardon, Aalderink, & van der Salm, 2007). Results from soil nitrogen model simulations have shown that the most damaging pollution is due to leached ammonium from urine and nitrate, arising due to cattle congregating (McGechan & Topp, 2004), and due to deposition at times of low plant nitrogen (N) uptake (Jarvis Sheerwood, & Steenvoorden, 1987; Fraser, Cameron, & Sherlock, 1994; Williams & Haines, 1994; Cuttle, 2001; Eriksen & Kristensen, 2001; von Wachenfelt, 2002; Decau, Simon, & Jacquet, 2003).

High animal density compacts the surface soil, obliterates the grass turf, impedes infiltration, decreases the aeration capacity of the soil and increases the amount of runoff from the surface (Chichester, van Keuren, & McGuiness, 1979; Warren, Thurow, Blackburn, & Garza, 1986; Koopmans, Chardon, & McDowell, 2007). Hanrahana, Jokela, & Knapp (2009) showed that reducing dietary P and extending the time between manure application and a rain event can significantly reduce concentrations of total P in runoff.

Pasture renovators (aerators) can increase pasture infiltration and reduce runoff by 45% (Moore, Formica, Van Epps, & DeLaune, 2004). Spreading manure patches after a grazing period can reduce their possible negative impacts on the environment (Chardon et al., 2007).

1.3 Geotextile pad constructions

A cost-effective way of producing all-weather surfaces for cattle is to use a combined geotextile-gravel pad construction, which enables the depth of the pavement construction to be decreased (KY-NRCS, 1998). These geotextile/gravel pad constructions have been used by US farmers as an all-weather surface for cattle since the 1990s and are reported to minimise mud, runoff and erosion in heavy traffic areas (Ruhl, Overmoyer, Barker, & Brown, 1997). Geotextiles are usually used in agriculture to keep different layers of gravel and soil separate. The geotextile improves the load bearing capacity and stability of the surface and promotes drainage and infiltration.

Because of the special drainage and infiltration qualities of geotextile, there could be a risk of surface water and groundwater contamination by nutrients in areas with cattle manure deposition, especially if the underlying soil has a permeable structure.

Other geotextile qualities such as filtration of liquid dairy manure (total solids (TS) = 0.71%) have been studied by Cantrell, Chastain, & Moore (2007), who found that geotextile filtration concentrated the solids and nutrients in the dewatered material 16- to 21-fold more than in the influent, retained 38.4% of TS, 25.8% of total ammoniacal nitrogen (TAN) and 45.0% of total phosphorus (TP), making this an effective liquid-solid separation technique.

In a study of runoff and drainwater quality from outdoor areas for cattle during winter, the drainage effluent concentrations of biochemical oxygen demand (BOD), chemical oxygen demand (COD), total nitrogen (TN) and TP were found to be reduced by 60-80% by a sandy soil column of 0.8 m depth including a geotextile fibre placed 300 mm below the soil surface, which was believed to have a trickling filter function (von Wachenfelt, 1998).

A number of studies have been carried out to determine whether using organic liners in combination with different manure types could decrease nitrogen seepage losses without using a geomembrane, concrete or asphalt (Barrington, Stilborn, & Moreno, 1995). Clogging effects in geotextiles, with the smallest pore opening size, exposed for liquid cattle slurry (TS = 7.5%) during 80 days were reported by Barrington, El-Moueddeb, Jazestani, and Dussault (1998). This could imply that geotextiles with small pore opening size could have a sealing effect against underlying soil, which could prevent nutrient leaching, deposition and groundwater pollution.

A pilot study was carried out by Bicudo, Goode, Workman, and Turner (2003) to determine the effect of different geotextile-gravel layer combinations (150-200 mm depth) on the vertical infiltration rate and contamination by beef cattle manure. Both TS and chemical oxygen demand (COD) values in the leachate were reduced by approx. 90%, but the amounts increased with precipitation and manure load.

In an investigation of runoff and leaching from geotextile pad constructions (200 mm) with 14 kg beef cattle manure and 50 mm h^{-1} rainfall applied, Singh, Bicudo, & Workman (2008) found a significant pad treatment effect on TS, COD, nitrite (NO_2-N), TN, TP in surface runoff, but no effect of manure removal on runoff composition except for ammonia (NH_4-N) concentration. Although only small amounts of organic matter were lost by runoff and leaching, the contamination level of runoff and leachate samples was high; TP of 12 mg l^{-1} in runoff and 10.6 mg l^{-1} NO_3-N in leachate. According to Singh et al. (2008), there were no available data in the literature related to runoff and drainage characteristics of geotextile-gravel pad constructions prior to their study.

Previous studies have shown that the environmental impact from COD, TN, TP and TS could be reduced in vertical transport through a geotextile pad construction, which would facilitate further treatment of the liquids in constructed wetlands (von Wachenfelt, 2003). The underlying soil material could be less contaminated if a dual-layer geotextile were used, as the upper layer could promote drainage while the layer below could have a sealing effect against underlying soil, preventing nutrient leaching and deposition and groundwater pollution.

In the study by Singh et al. (2008), the main focus was on runoff and leachate in response to pad construction, manure application and rainfall, where leachate and drainage effluent were treated as one and the same factor.

Table 1. Physical characteristics for the geotextiles used in the test as single or in combination.

	Standard	Units	Propex 6083*	Typar SF20**	Protexia FC 021***
Polymer			Polypropylene	Polypropylene	Polypropylene
Mass per Unit Area	EN 9864	g/m2	252	68	****
Thickness, mm	EN 9863	mm	1.3	0.28-0.35	
Tensile strength, T_{max}	EN ISO 10 319	kN/m	60	3.4	8
Water permeability normal to plane	EN ISO 11 058	mm/s	30	180	120
Pore size, O_{90}	EN ISO 12956	µm	200	225	85
In plane flow capacity at 20 kPa	EN ISO 12958	l/s/m width		5.2	7

* PROPEX fabrics, Gronau, Germany, main strengthening geotextile (Single)
** Typar Geosynthetics, Luxembourg, filtering geotextile, placed above single geotextile (Non-woven above)
** GEOfabrics limited, Leeds, UK, filtering geotextile, placed under single geotextile (Non-woven under)
**** Roll weight of 1*50 m is 58 kg, including cuspated drainage

The overall aim of the present study was to identify the geotextile/gravel pad construction that resulted in the least contaminated runoff and drainage effluent when exposed to moderate to heavy precipitation and different manure loads. Specific objectives were to: determine whether a geotextile-gravel layer construction gives acceptable sealing to the underlying soil surface when exposed to the manure load from high animal density areas; identify the combination of geotextile and gravel that offers the best drainage effect (i.e. the least runoff if exposed to rainfall and the manure load from high animal density areas); and determine the quality of runoff and drainage effluent from a geotextile-gravel pad with regular manure removal and manure accumulation.

The hypothesis was that a 200 mm geotextile-gravel pad construction would offer sufficient infiltration of runoff, drainage efficiency and sealing towards the underlying soil surface to replace a membrane (see treatment B3).

2 Materials and methods

2.1 Experimental design

Two field experiments were conducted in four different test areas with geotextile-gravel combinations in a split-plot design. All plots had a geomembrane and 50 mm sand in the bottom. Treatments were as follows (from bottom to surface):

B1. Non-woven (Protexia FC 021) and woven geotextile (Propex 6083), 150 mm of gravel (16-32 mm) and 50 mm of gravel (8-16 mm).
B2. Woven (Propex 6083) and non-woven geotextile (Typar SF20), 150 mm of gravel (16-32 mm) and 50 mm of gravel (8-16 mm).
B3. Woven geotextile (Propex 6063), 150 mm of gravel (16-32 mm) and 50 mm of gravel (8-16 mm).
B4. Control*: 150 mm of gravel (16-32 mm) and 50 mm of gravel (8-16 mm).

Treatments were chosen on the basis of previous experiments by Singh et al. (2008). Treatment B3 was based on specifications from Kentucky Natural Resources Conservation Service (KY-NRCS, 1998). A gravel plot (Gravel) was used as the control*.

Geotextile physical characteristics are given in Table 1. Propex 6083 (Single) is the main strengthening geotextile in all pad constructions. Typar (Non-woven above) is a filtering geotextile placed above Single geotextile which could limit drain fluid TS concentration and promote areation of organic nutrients. Protexia FC 021 (Non-woven under) is a filtering geotextile mounted on a cuspated drainage, placed under Single geotextile to minimise leachate concentrations.

Table 2. Composition of beef cattle manure, (n = 4 per sample).

Experiment	Sample	TN[1] kg t^{-1}	TAN[2] kg t^{-1}	TP[3] kg t^{-1}	C/N[4]	Ashes %	Ts[5] %
Manure removal at the end of experiment	1	5.5	1.8	1.1	19	2.5	16.9
	2	5.6	1.7	1.0	18	2.3	16.0
	3	6.7	1.9	1.0	14	2.4	16.2
	4	5.7	1.8	1.0	16	2.2	15.0
	5	6.0	1.8	1.1	17	2.6	17.0
Manure accumulation	6	7.1	2.2	1.2	17	2.9	19.8
	7	7.8	2.3	1.2	16	1.9	19.4
	8	4.8	1.7	0.9	16	2.5	12.6
	9	5.7	1.9	1.0	20	2.0	17.4
	10	4.1	1.7	0.7	17	3.1	11.3

1) TN - total nitrogen; 2) TAN - total ammoniacal nitrogen; 3) TP - total phosphorus;
4) C/N - carbon nitrogen ratio; 5) TS – total solids.

Beef cattle manure was added to the test area before each experiment. The manure was applied in two ways. In the first experiment, the manure was applied and then removed (manure removal), while in the second experiment the manure was allowed to accumulate on the test area surfaces (manure accumulation).

2.2 Test area construction

The experiments were conducted using eight plots measuring 2 m by 6 m at the Swedish University of Agricultural Sciences, Alnarp. The test areas had a uniform 3% slope along the major axis and cross-levelled along the minor axis.

Each plot was bordered by tongue and groove timber held in place by wooden posts. The slope and levelling inside were created by filling and on top of that was placed a PVC membrane, which had a low point gutter for trapping leachate (Fig. 1).

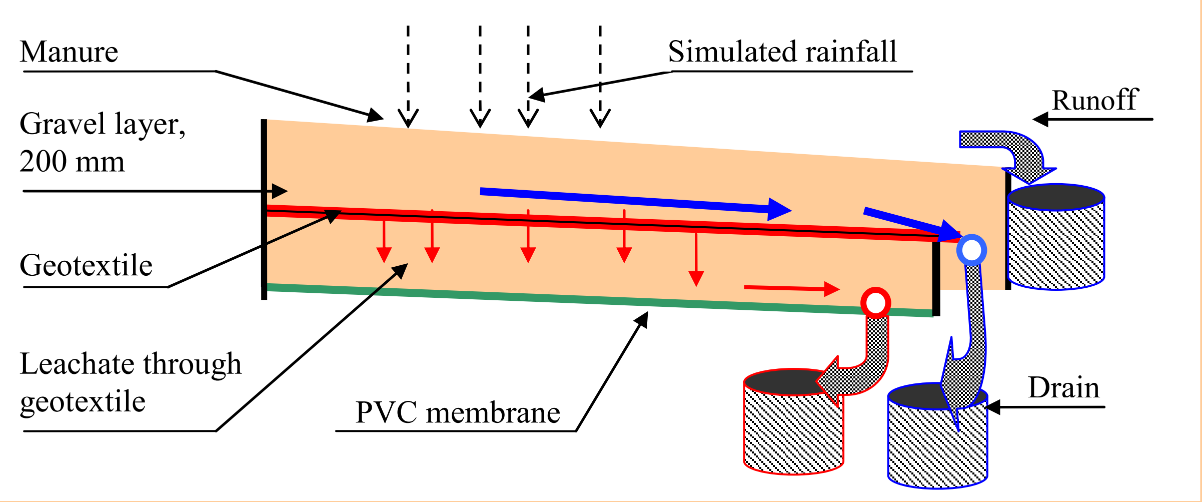

Fig. 1. Cross-section of the test pad construction.

Above the membrane, a layer of coarse sand created a space for leachate trapping. The sand bed was covered with single geotextile or geotextile combination, which in turn was covered with a 150 mm layer of coarse gravel (16-32 mm) and a 50 mm layer of 8-16 mm gravel.

The drainage outlet was separated from the leachate water trap by a shoulder, and the geotextile material covering the sand bed was drawn over this shoulder so that the drainage effluent was discharged into a separate trap. The function was tested prior to covering the plot with gravel. Both leachate and drainage effluent were collected for measurement and sampling through 50 mm i.d. plastic pipe, which had a flange on either side of the wooden panel that could be fastened to prevent leakage. The collection area for the drainage effluent was the total plot area (12 m^2), while the leachate was collected from an area of 11 m^2, (Fig 1).

A gutter was installed across the lower end of the plot to collect runoff for sampling and measurement. Runoff, drainage effluent and leachate were sampled as they exited the respective pipes and liquids were discharged into a collection sump and discharged from there into an adjacent drain system.

2.3 Manure characteristics

The manure was applied at a rate of 15 kg per plot area (1.25 kg m^{-2}) simulating a stocking density of 6 beef cattle for four hours per day (Kemira, 2001). Manure, with almost no bedding material, was obtained from a farm with a housing system for beef cattle using a manure aisle behind the feeding alley. The manure was stored in cold storage prior to the experiment and was properly mixed and sampled before application to the test area. The ambient temperature was 17±4°C and the humidity 52±18% during the experimental period.

The manure samples were analysed for total nitrogen (TN), total ammoniacal nitrogen (TAN), total phosphorus (TP), carbon nitrogen ratio (C/N) and total solids (TS) according to ISS (2003). The manure composition complied with that of normal beef cattle manure (Kemira, 2001), Table 2.

2.4 Sampling of runoff, drainage effluent and leachate

To simulate an outdoor area with cattle manure during a rain storm event a rainfall simulator capable of applying 0-70 mm/hour to one 2 m x 6 m plot at a time was used to generate runoff and drainage effluent from the plots (Fig. 2).

Fig. 2. Rainfall simulator at work

The rainfall simulator worked like a crop sprayer, with sprayers mounted on a boom which travelled back and forth over the plot. The sprayers were calibrated before each run and the plots were pre-wetted before the manure was applied. The pre-wetting of the plot was done to prevent a time lag in building a uniform flow at the measuring points after manure application. The simulated rainfall was kept at 50 mm h^{-1} for 30 minutes or until runoff occurred.

The pre-wetting was stopped when continuous water flow was visible at all outlets. As soon as the pre-wetting process had stopped completely, manure was applied manually to the plot and the rainfall simulator was started again at a rate of 50 mm h^{-1} for 30 minutes.

The outgoing fluids were sampled at 2, 4, 6, 8, 16, 24, 32 minutes and at 1, 3, 5, 7, 15, 23, 31 minutes after the rainfall simulator stopped, respectively. The fluids were sampled directly from each flow stream in graduated 1-litre jars, one for each measuring point. The fluids from each measuring point was collected in a bucket and then sampled by intermittent sampling into one sample for each measuring point. Sample collection was for 60 seconds or until the jar was filled. The time required to collect an individual sample was measured by a stopwatch graded in 100ths of a minute.

The runoff was automatically sampled into a flow-weighted composite sample as the total amount of sampled fluid was of normal sample size. The other two sampling points received less fluid over time, which meant that with an intermittent sampling method the fluids were flow-weighted indirectly.

All samples were frozen directly after sampling. The samples were analysed for total nitrogen (TN), total ammoniacal nitrogen (TAN), nitrate (NO_3-N), nitrite (NO_2-N), total phosphorus (TP), chemical oxygen demand (COD) and total solids (TS) according to ISS (2003).

The fluid volumes were calculated by numerical integration (trapezoid) of runoff, drainage effluent and leachate rates with respect to time. Mass values were obtained by multiplying the fluid concentrations of each constituent by the respective fluid volume.

2.5 Statistical analysis

The experimental design was a split-plot design without blocks with manure removal or accumulation as main plot factor and treatments B1-B4 as split-plot factor. An analysis of variance PROC MIXED in SAS Institute Incorp. (2003) was performed to determine the effect of manure removal or accumulation and treatment combinations on the content of TS, COD and nutrients in sample fluids as well as in the fluid flow. The data from manure removal and accumulation could have been confounded over time as the manure was deposited on the pads, but the intermediate time between weighing, sampling and manure application was very short. A significance level of 5% was used throughout the analysis and Tukey's method was used to separate least-square means for treatments. The results are presented as mean and standard deviation (SD). The statistical model used was

$$Y_{ijkl} = \mu + \alpha_i + \beta_j + (\alpha\beta)_{ij} + \gamma_{k(i)} + e_{ijkl}$$

where μ = treatment mean, α_i = manure removal or accumulation, β_j = geotextile test area treatment, $\gamma_{k(ij)}$ = random effect of replication, e_{ijk} = error term, i = manure level (1, 2), j = geotextile test area treatment level (1, 2, 3, 4), k = number of main plots (1, 2, 3, 4, 5) and l = number of replicates in each main plot (1, 2).

3. Results

3.1 Fluid flow rate

The fluid flows through the geotextile gravel pads are shown in Table 3 for each experimental set-up. The runoff was low because of the coarse gravel material on top of the pads, which kept the runoff at the same rate in both experiments. The drainage effluent flow rate ranged between 246 and 307 l m^{-2} h^{-1} and the leachate flow rate between 42 and 179 l m^{-2} h^{-1} in the with manure removal experiment, while corresponding flow rates were 272-324 and 26-88 l m^{-2} h^{-1} respectively with manure accumulation experiment. The mean drainage and leaching rate decreased on average by 10 and 80% respectively during the two experiments.

Table 3. Fluid flow in the geotextile-gravel beds in liters per m^2 and h. Comparison between different geotextile material combinations and between manure accumulation and removal (number of samples (n), least square means and standard deviation (SD)).

Parameter		Treatment								
		Non-woven under		Non-woven above		Single (woven geotextile)		Gravel		
	n	Mean (SD)	p^1	Mean (SD)	p^1	Mean (SD)	p^1	Mean (SD)	p^1	p^2
Manure removal										
Runoff (lm^{-2}h^{-1})	10	6 (1)	ns	8 (3)	ns	7 (2)	ns	5 (2)	ns	ns
Drain (lm^{-2}h^{-1})	10	293 (23)	ns	246 (27)	***	251 (79)	ns	307 (24)	ns	ns
Leachate (lm^{-2}h^{-1})	10	42 (13)^a	ns	179 (70)^b	***	124 (53)^b	ns	0	ns	***
Manure accumulation										
Runoff (lm^{-2}h^{-1})	10	7 (2)		7 (1)		6 (2)		6 (4)		ns
Drain (lm^{-2}h^{-1})	10	293 (44)		324 (75)		272 (62)		302 (14)		ns
Leachate (lm^{-2}h^{-1})	10	26 (23)^a		79 (44)^b		88 (45)^{ab}		0		**

[1)] Significance level comparing manure removal and accumulation: * = $p<0.05$; ** = $p<0.01$; *** = $p<0.001$; ns= non significant
[2)] Different superscripts denote significant differences comparing treatments.

Table 4. Runoff fluid concentration in the geotextile-gravel beds in mg per liter. Comparison between different geotextile material combinations (treatments) and between manure accumulation and removal (number of samples (n), least square means and standard deviation (SD)).

Parameter		Treatment					
		Non-woven under	Non-woven above	Single (woven geotextile)	Gravel		
	n	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	p^1	p^2
Runoff, manure removal							
Total N (mgl^{-1})	10	28.8 (8.3)	27.0 (8.8)	31.6 (10.6)	29.0 (12.8)	ns	ns
TAN (mgl^{-1})	10	11.0 (5.5)	7.8 (4.4)	11.2 (7.6)	11.0 (7.4)	ns	ns
NO_3-N (mgl^{-1})	10	0.09 (0.00)	0.09 (0.00)	0.09 (0.00)	0.11 (0.07)	ns	ns
NO_2-N (mgl^{-1})	10	0.02 (0.02)	0.04 (0.03)	0.05 (0.05)	0.03 (0.02)	ns	ns
Total P (mgl^{-1})	10	4.6 (0.9)	4.6 (0.8)	5.4 (1.3)	4.6 (2.0)	ns	ns
COD (mgl^{-1})	10	625 (236)	589 (208)	764 (369)	634 (340)	ns	ns
TS (mgl^{-1})	10	790 (197)	741 (165)	886 (283)	795 (259)	ns	ns
Runoff, manure accumulation							
Total N (mgl^{-1})	10	28.2 (11.1)	22.7 (7.4)	24.0 (5.6)	33.4 (11.4)		ns
TAN (mgl^{-1})	10	8.7 (4.7)	8.1 (4.3)	9.5 (3.2)	12.1 (7.5)		ns
NO_3-N (mgl^{-1})	10	0.09 (0.00)	0.09 (0.00)	0.09 (0.00)	0.09 (0.00)		ns
NO_2-N (mgl^{-1})	10	0.03 (0.02)	0.06 (0.06)	0.06 (0.03)	0.06 (0.04)		ns
Total P (mgl^{-1})	10	5.1 (2.0)	4.4 (1.1)	5.1 (1.6)	6.5 (1.7)		ns
COD (mgl^{-1})	10	610 (290)	522 (181)	578 (123)	746 (179)		ns
TS (mgl^{-1})	10	912 (279)^{ab}	760 (173)^b	795 (96)^{ab}	1060 (196)^a		*

[1)] Significance level comparing manure removal and accumulation: * = $p<0.05$; ** = $p<0.01$; *** = $p<0.001$; ns= non significant
[2)] Significance level comparing different treatments. Different superscripts denote significant differences comparing treatments.

For treatment 'Non-wowen above' the leachate flow decreased from 179 to 79 l m-2 h-1 beween the experiments and with manure removal experiment treatment 'Non-woven under' gave significantly lower leaching (42 l m-2 h-1) than treatments ‘Non-woven above’ and ‘Single’. With manure accumulation, the leachate flow in the treatments was significantly different for all pads and amounted to 26, 79, and 88 l m^{-2} h^{-1} for treatment ‘Non-woven under’, ‘Non-woven above’ and ‘Single’, respectively.

The reference pad (Gravel) had the same flow in both experiments, with a relatively small SD. The SD for leaching from manure removal pads was less than that from manure accumulation pads, while for the other fluids the SD was of the same range and order in both experiments. There were individual differences between replicates, showing that the leaching in the’Non-woven under’ treatment was almost insignificant at the end of the experiments.

3.2 Runoff

The effects of the treatments and manure application with and without removal are shown in Table 4 and 7. No differences in nitrate or nitrite levels were found during the experiments. The average concentration of nitrate in runoff was 0.09 mg l^{-1} and that of nitrite was 0.05 mg l^{-1}. For TS in runoff there was a treatment and experiment∗treatment effect, with a lower TS value of 760 mg/L (90 mg m^{-2}) for treatment ‘Non-woven above’ compared with ‘Gravel’ (1060 mg l^{-1}; 94 mg m^{-2}) with manure accumulation.

3.3 Drainage effluent

An experimental effect was found for TN in drainage effluent, with a decrease in the TN value (20 mgl^{-1}) for manure removal compared with manure accumulation (26 mg l^{-1}). The nutrient content per unit area for manure removal (92 mg m^{-2}) was 26% lower than for manure accumulation.

Table 5. Drain fluid concentration in the geotextile-gravel beds in mg per liter. Comparison between different geotextile material combinations (treatments) and between manure accumulation and removal (number of samples (n), least square means and standard deviation (SD)).

Parameter		Treatment					
	n	Non-woven under Mean (SD)	Non-woven above Mean (SD)	Single (woven geotextile) Mean (SD)	Gravel Mean (SD)	p^{1}	p^{2}
Drain, manure removal							
Total N (mgl^{-1})	10	21.0 (6.0)	19.0 (2.6)	18.9 (1.8)	21.7 (4.8)	*	ns
TAN (mgl^{-1})	10	6.7 (2.7)	5.1 (2.0)	5.1 (1.2)	6.1 (2.5)	ns	ns
NO_3-N (mgl^{-1})	10	0.15 (0.10)	0.14 (0.07)	0.14 (0.08)	0.09 (0.00)	ns	ns
NO_2-N (mgl^{-1})	10	0.32 (0.33)^{a}	0.23 (0.16)^{ab}	0.31 (0.37)^{ab}	0.07 (0.06)^{b}	ns	*
Total P (mgl^{-1})	10	3.5 (0.6)	3.6 (0.6)	3.6 (0.4)	3.8 (0.6)	***	ns
COD (mgl^{-1})	10	413 (63)	394 (75)	407 (50)	443 (81)	***	ns
TS (mgl^{-1})	10	647 (77)^{a}	619 (41)^{b}	625 (51)^{ab}	618 (80)^{ab}	***	*
Drain, manure accumulation							
Total N (mgl^{-1})	10	28.3 (8.7)	23.5 (6.7)	23.7 (4.5)	28.3 (4.1)		
TAN (mgl^{-1})	10	8.7 (4.7)	6.6 (2.9)	7.9 (2.8)	8.4 (2.3)		
NO_3-N (mgl^{-1})	10	0.47 (0.87)	1.22 (2.14)	0.36 (0.79)	0.09 (0.00)		
NO_2-N (mgl^{-1})	10	0.32 (0.24)	0.16 (0.13)	0.17 (0.17)	0.12 (0.06)		
Total P (mgl^{-1})	10	5.5 (1.7)	4.5 (1.2)	5.2 (0.7)	5.8 (0.9)		
COD (mgl^{-1})	10	580 (160)	542 (131)	567 (39)	619 (90)		
TS (mgl^{-1})	10	941 (186)	769 (171)	817 (68)	911 (104)		

1) Significance level comparing manure removal and accumulation: * = $p<0.05$; ** = $p<0.01$; *** = $p<0.001$; ns= non significant

2) Significance level comparing different treatments (mean of manure removal and accumulation). Different superscripts denote significant differences comparing treatments.

A treatment effect was found for NO_2-N (Table 5), which occurred in the highest concentration (0.32 mg l^{-1}) in the drainage effluent from treatment ‘Non-woven under’ in both experiments, (1.63 and 1.56 mg m^{-2} in manure removal and manure accumulation experiment respectively). The control (Gravel) had the lowest values, 0.07 mg l^{-1} (0.35 mg m^{-2}) and 0.12 mg l^{-1} (0.58 mg m^{-2}) in manure removal and manure accumulation experiment respectively. The NO_2-N concentration in drainage effluent from treatments ‘Non-woven above’ and

‘Single’ was intermediate and not significantly different from the other treatments. The average nitrite and nitrate concentrations in the drainage effluent were 0.4-0.7 and approx. 1.0 mg m^{-2} pad area, respectively.

TP, COD and TS in drainage effluent showed an experimental effect due to manure application, with a mean reduction in concentration (mg l^{-1}) of 31, 28 and 27%, respectively, due to manure removal. The mean COD reduction ranged from 577 mg l^{-1} (2813 mg m^{-2}) to 414 mg l^{-1} (1904 mg m^{-2}) with manure removal. The effect of treatment on TS concentration was also significantly lower for ‘Non-woven above’ with manure accumulation, 694 mg l^{-1} (3284 mg m^{-2}), compared with the other treatments.

3.4 Leachate

In leachate determination there were no measurements for treatment Gravel (control), as this plot only worked as reference in runoff and drainage effluent concentrations, with no geotextile used. In comparing drainage effluent and leachate, all concentrations were lower in leachate except for NO_3-N and NO_2-N, which increased over time. With manure removal the concentrations in leachate were lower except for NO_2-N, but measured by nutrient content per m^2 pad area, all parameters except NO_3-N had a decreasing tendency, mainly due to decreased leaching rate.

Table 6. Leachate fluid concentration in the geotextile-gravel beds in mg per liter. Comparison between different geotextile material combinations (treatments) and between manure accumulation and removal (number of samples (n), least square means and standard deviation (SD)).

Parameter		Treatment					
	n	Non-woven under Mean (SD)	Non-woven above Mean (SD)	Single (woven geotextile) Mean (SD)	Gravel[3] Mean (SD)	p^1	p^2
Drain, manure removal							
Total N (mgl^{-1})	10	9.6 (2.3)	9.5 (2.7)	9.2 (1.8)	0	***	ns
TAN (mgl^{-1})	10	1.7 (1.2)	1.7 (0.5)	1.7 (1.1)	0	ns	ns
NO_3-N (mgl^{-1})	10	2.87 (3.72)^{a}	0.48 (0.22)^{b}	1.61 (1.60)^{ab}	0	***	*
NO_2-N (mgl^{-1})	10	0.25 (0.14)^{a}	0.57 (0.48)^{a}	0.38 (0.40)^{a}	0	ns	*
Total P (mgl^{-1})	10	1.1 (0.4)	1.3 (0.4)	1.0 (0.4)	0	*	ns
COD (mgl^{-1})	10	130 (64)^{b}	188 (90)^{a}	146 (55)^{b}	0		*
TS (mgl^{-1})	10	445 (48))	432 (68)	428 (40)	0	***	ns
Drain, manure accumulation							
Total N (mgl^{-1})	10	14.7 (3.0)	15.1 (1.9)	13.9 (2.3)	0		
TAN (mgl^{-1})	10	1.6 (1.2)	2.4 (0.9)	1.9 (0.8)	0		
NO_3-N (mgl^{-1})	10	7.78 (4.73)	3.95 (4.22)	5.82 (2.09)	0		
NO_2-N (mgl^{-1})	10	0.24 (0.13)^{a}	0.11 (0.04)^{b}	0.12 (0.07)^{b}	0		
Total P (mgl^{-1})	10	1.4 (0.9)	1.8 (0.7)	1.2 (0.4)	0		
Total COD (mgl^{-1})	10	175 (100)	241 (90)	167 (54)	0		
Total TS (mgl^{-1})	10	575 (111)	576 (75)	533 (70)	0		

1) Significance level comparing manure removal and accumulation: * = $p<0.05$; ** = $p<0.01$; *** = $p<0.001$; ns= non significant

2) Significance level comparing different treatments (mean of manure removal + accumulation). Different superscripts denote significant differences comparing treatments.

3) The gravel treatment did not contain any geotextile material and thus had no leachate.

An experimental effect was found on leachate concentration for TN, NO_3-N and NO_2-N, with the first two parameters decreasing by 34 and 70% respectively, while NO_2-N increased by 60% for manure removal compared with manure accumulation. The TN and NO_2-N concentration in leachate per m^2 pad area (mg m^{-2}) decreased by 14 and 85%, respectively, with manure accumulation, while the NO_3-N content increased by 185%.

A treatment effect of higher NO_3-N concentration was found for treatment ‘Non-woven under’ compared with ‘non-woven above’, but there was no significant effect for ‘Single’.

The NO_2-N concentration had an experiment∗treatment effect in that it was 0.11 and 0.12 mg l^{-1} for ‘Non-woven above’ and ‘Single’, respectively, with manure accumulation but significantly higher, 0.57 and 0.38 mg l^{-1}, respectively, with manure removal. The average NO_3-N concentration in leachate was 2.2-6.2 mg m^{-2} pad surface and the average NO_2-N concentration approx. 1.1-0.2 mg m^{-2} pad surface for manure removal and manure accumulation respectively.

Table 7. A comparison of nutrient content, expressed per unit pad area (mgm^{-2}), in runoff, drain and leachate as an effect of manure removal and accumulation and different geotextile-gravel bed treatments (number of samples (n), mean and standard deviation (SD)).

Parameter	n	Treatment			
		Non-woven under Mean (SD)	Non-woven above Mean (SD)	Single (woven geotextile) Mean (SD)	Gravel Mean (SD)
Manure removal					
Runoff TS (mgm^{-2})	10	82 (23)	95 (19)	98 (21)	79 (21)
Drain total N, mg/m^2	10	102 (27)	77 (8)	79 (10)	111 (22)
Drain NO_2-N, mg/m^2	10	1.63 (1.21)	0.92 (0.45)	1.33 (0.99)	0.35 (0.24)
Drain total P, mg/m^2	10	17.0 (1.7)	14.8 (1.3)	14.9 (2.9)	19.3 (3.0)
Drain COD, mg/m^2	10	2007 (221)	1607 (117)	1733 (318)	2268 (402)
Drain TS, mg/m^2	10	3151 (316)	2526 (143)	2629 (288)	3161 (411)
Leachate total N, mg/m^2	10	7.1 (2.1)	32.9 (9.0)	21.8 (6.7)	
Leachate NO_3-N, mg/m^2	10	1.53 (0.74)	1.42 (0.48)	3.58 (2.67)	
Leachate NO_2-N, mg/m^2	10	0.21 (0.13)	1.92 (1.01)	1.02 (0.89)	
Leachate total P, mg/m^2	10	0.9 (0.4)	4.7 (1.5)	2.4 (1.3)	
Leachate COD, mg/m^2	10	110 (60)	708 (307)	353 (184)	
Leachate TS, mg/m^2	10	343 (77)	1475 (339)	990 (323)	
Manure accumulation					
Runoff TS, mg/m^2	10	100 (40)	90 (24)	77 (10)	94 (45)
Drain total N, mg/m^2	10	134 (21)	119 (9)	107 (15)	142 (12)
Drain NO_2-N, mg/m^2	10	1.56 (1.19)	0.90 (0.52)	0.79 (0.51)	0.58 (0.23)
Drain total P, mg/m^2	10	26.5 (6.2)	23.5 (3.4)	23.3 (2.1)	29.4 (4.1)
Drain COD, mg/m^2	10	2758 (460)	2787 (505)	2594 (269)	3112 (252)
Drain TS, mg/m^2	10	4509 (571)	4043 (756)	3734 (211)	4578 (443)
Leachate total N, mg/m^2	10	7.5 (0.9)	22.3 (10.8)	23.3 (5.6)	
Leachate NO_3-N, mg/m^2	10	2.40 (1.22)	6.62 (1.97)	9.59 (2.86)	
Leachate NO_2-N, mg/m^2	10	0.10 (0.06)	0.16 (0.06)	0.23 (0.11)	
Leachate total P, mg/m^2	10	0.9 (0.4)	2.4 (1.3)	2.1 (0.4)	
Leachate COD, mg/m^2	10	110 (42)	315 (151)	285 (58)	
Leachate TS, mg/m^2	10	295 (52)	820 (386)	861 (180)	

An experimental effect was found for TP and TS, with approx. 30% increase in the mean concentration of TP (from 1.1 to 1.5 mg l^{-1}) and in TS (from 435 to 561 mg l^{-1}) between manure removal and manure accumulation. However, the total content per m^2 of TP and TS decreased by approx. 30% respectively due to less fluid flow in manure accumulation experiment. For leachate there was a treatment effect on COD concentration for ‘Non-woven under’ and ‘Single’, with 29 and 27% reduction, respectively compared with ‘Non-woven above’. For ‘Non-woven under’ and ‘Single’ this meant a reduction in COD and TS content per m^2 of 79 and 63% with manure removal and 34 and 5% with manure accumulation compared with the overall mean for the experiments.

4. Discussion

4.1 Main findings

The pad surface layer reduced runoff flow and the drain flow generated was stable throughout the experiments, confirming pad stability. Manure removal reduced TN, TP, COD and TS concentrations in drainage effluent. One pad construction (Non-woven under) proved to be a better oxidiser of NO_2-N and another (Non-woven above) a better trap for TS. Leachate and drainage effluent composition were equally affected by manure removal and one pad construction (Non-woven under) met the sealing liner norm to the underlying soil. The drainage effluent concentrations were acceptable for wetland treatment.

4.2 Fluid flow rate

The use of coarse gravel as the top layer of the pad construction in this study reduced the runoff flow rate and increased leaching through the pad profile by 1000-fold per m^2 compared with that of Singh et al. (2008). There was no evident change in drainage flow capacity in the present study, which is in accordance with Singh et al. (2008).

The leachate flow rate decreased in individual pads. This continual decrease in leachate flow and in leachate contaminant concentrations could be an effect of biological sealing by the geotextile as shown by Barrington et al. (1998). The average nitrogen seepage rate of the pads (1.1 g m^{-2} d^{-1} in both experiments) exceeded the required norm of 0.6 g m^{-2} d^{-1} for a sealed liner by most North American Environmental Authorities. For the ‘Non-woven under’ pad the seepage rate was equal to or below the norm (0.6 and 0.5 g m^{-2} d^{-1} with manure removal and accumulation respectively). An overall declining nitrogen seepage rate was also found for the other treatments, which could imply that the sealing effect would have occurred in all pads if the experimental period had been longer.

The manure used in the study had low concentrations of all contaminants but especially TP and COD compared to Singh et al. (2008). Unfortunately the COD value of the manure was not analysed, and the highest values found in runoff were 81% lower than those reported by Singh et al. (2008). However, the nutrient content of the manure, without bedding, conformed to Scandinavian standards for beef cattle (Kemira, 2001).

4.3 Runoff

Almost all response parameters measured in runoff from the pad constructions had low values compared with drainage effluent and leachate, but also compared with values reported by Singh et al. (2008). The most probable explanation is the low amount of runoff and the immediate infiltration of fluid into the pad profile in the present study. The nitrate and nitrite concentration in runoff managed to meet the Swedish drinkable water norms of < 50 mg l^{-1} nitrate and < 0.5 mg l^{-1} nitrite.

The TP level in runoff was 5 mg l^{-1} (0.5 mg m^{-2}), compared with approx. 2.0 mg m^{-2} for Singh et al. (2008), which was considered high (ASAE 2005). In the present study the combined treatment and experiment$*$treatment effect resulted in treatment ‘Non-woven above’ having a 28% lower TS content than the control (Gravel) with manure accumulation. Singh et al. (2008) found a similar effect when comparing densely graded aggregate (DGA) surfaced plots with a mud plot, with weekly removal. The TS levels in the present study were lower than the lowest TS values reported by Singh et al. (2008).

4.4 Drainage effluent

An overall reduction in contaminant concentrations in drainage effluent was observed in all plots as the fluid passed through the geotextile and gravel layer or only the gravel layer. For TN, TP, COD and TS, nutrient concentrations in the drainage effluent were lower with manure removal. For NO_2-N and TS, the different treatments showed that 'Non-woven under' probably had a better oxidising effect in its profile, producing the highest NO_2-N value, while 'Non-woven above' was the best pad at trapping TS during manure accumulation. Manure removal had an effect on TS which could be observed in all treatments, but in the case of manure accumulation the results from 'Non-woven above' could probably be explained by the action of the non-woven geotextile above the main draining geotextile. The entrapment of TS would be beneficial in reducing clogging before treating the effluent in constructed wetland (von Wachenfelt, 2003).

The NO_2-N level in drainage effluent was twice the drinkable water norm according to Swedish Standards (0.5 mg l^{-1}). The decrease in NH_4-N and limited increase in NO_3-N and NO_2-N levels recorded in drainage effluent were promising effects but the manure in this experiment was not complemented by urine, which has a high nitrogen potential and would probably have increased the nutrient levels. Within the geotextile-gravel pad construction, oxidation of organic matter was apparent as an increase in NO_3-N and NO_2-N, but the oxidation process would probably have been more pronounced if the experiment had run for a longer period, with intermittent dry and wet periods (von Wachenfelt, 1998).

With the measuring technique that was applied in this experiment, with pre-wetting and direct application of water after manure application, the amount of ammonia volatilisation could be neglected, but in the real case there would be a potential for ammonia volatilisation which was not measured in this experiment, especially with manure accumulation.

The overall outcome was that the drainage effluent was affected by manure removal for most of the parameters, and that the composition of the drainage effluent matched measured values from an outdoor winter facility for cattle (von Wachenfelt, 1998). A liquid waste with the concentrations measured would be suitable for treatment in a constructed wetland (von Wachenfelt, 2003). As for the porous surface design, runoff could be expected to amount to less one-third of precipitation on these areas (White, 1973; von Wachenfelt, 2002).

4.5 Leachate

The reduction in nutrient concentrations in leachate from all plots was even higher than in the drainage effluent. Manure removal played a major part in this for all but two parameters, while for two parameters (TS, NO_3-N) there was a treatment effect. The aspect of flow rate is mentioned above, especially for leachate. The leachate trap construction (Fig. 1), with geotextile separating the sand from the coarse gravel and sand filling, probably brought about a reduction in leachate nutrient concentrations, but to allow comparisons of other parameters the construction was the same for all treatments.

The range of TN concentrations in leachate (9.4-29.1 mg l^{-1}) agreed with that of Singh et al. (2008), but in the present study the manure removal had an effect on TN values in leachate from the treatments, unlike in the study by Singh et al. (2008). This could be due to the manure removal procedure in the present study, where the manure was removed after measurements were made. All nitrogen nutrients decreased in concentration in leachate except NO_3-N, which increased with organic material content with manure accumulation. The levels of NO_3-N observed in this study were in the range reported by Singh et al., (2008), were but generally lower for both manure removal and manure accumulation, probably as a result of lower nutrient concentration in the manure used here. In the present study there was a treatment response for NO_3-N in the treatments using 'Non-woven under' and 'Non-woven above' the main (Single) geotextile, and a similar trend was found for the non-woven pad treatment by Singh et al. (2008) study, although no treatment effect was found. The leakage NO_2-N exceeded the Swedish drinkable water norm of 0.5 mg l^{-1} in periods.

With increased manure loading there was more potential for organic nitrogen to be converted to mineral nitrogen by bacteria in the geotextile and gravel pads. As nitrogen leached through the gravel pad profiles, a fraction could have been immobilised due to reaction with minerals contained in the gravel. Other fractions of the nitrogen could have been converted into NO_3-N or NO_2-N, due to large pore size and good air entrapment. This oxidisation process could also have been further enhanced in manure removal experiment by the non-woven geotextile, especially in 'Non-woven above', but also by the Single woven geotextile.

Manure accumulation had an effect on both TP and TS (Table 6). Manure removal lowered the TP by 23% to 1.15 mg l^{-1}, but with lower fluid flow the TP nutrient content per m^2 (1.82 mg m^{-2}) was reduced by 47% with manure accumulation compared with removal. A similar trend was observed for TS. The TS value was lowered 29% by manure removal, to 435 mg l^{-1}, but with the lower fluid flow the total amount of TS (659 mg l^{-1}) decreased by 42% with manure accumulation compared with manure removal.

Geotextile-gravel pad treatments had an effect on leachate COD in both B1 and B3, with the lowest leachate COD values of 152 and 156 mg l^{-1}. However with lower fluid flow the nutrient content per m^2 of leakage COD of pad B1 was approx. 110 mg m^{-2} with both manure removal and accumulation, whereas in B3 the leachate COD value fell from 353 to 285 mg m^{-2} with manure accumulation compared with removal.

The COD values reported by Singh et al. (2008) were lower (61.3 mg l^{-1}, 27 mg m^{-2}) than in the present study. Singh et al. (2008) noted no treatment effect on COD values but the geotextile-gravel pads tended to contain more COD than a reference mud plot. The trend in the present study was for declining COD concentrations with both manure removal and accumulation due to lower fluid flow.

A combination of all three pad constructions could probably give all the benefits of the individual pad surfaces. The pad construction enables any other surface pavement to be added like straw or wood ships and still be able to reduce runoff. The geotextile combination 'Non-woven under' and 'above' show that the drainage effluent will be able to reduce organic N and trap TS in a large filtering area. As for leachate treatment and reduction the experiment showed promising results but needs a longer test period to obtain reliable data.

4.6 Mass balance

A mass balance calculation was performed to estimate the losses of nutrient from the treatments. Average values of nutrients, COD and TS were calculated from the experiments with manure removal and manure accumulation. The losses of nutrients, COD and TS were similar in all treatments and with both manure removal and accumulation. As no COD values were available for the manure, COD was not estimated. Up to 99.4% of the nutrients were retained on the pad surface with part being volatilised to the atmosphere, ~0.01% lost in runoff, 0.5% lost in drainage effluent and 0.06% lost in leachate. Although a very small proportion of organic matter and nutrients was lost through runoff, drainage effluent and leachate, the actual level of contamination could be high (Singh et al., 2008), especially if no post-treatment takes place.

4.7 Economics

When a geotextile is used, the depth of the stabilising rock-gravel material can be roughly halved while still maintaining the draining qualities of the material. The geotextile also means that different material sizes can be effectively separated from each other and from soil material. The cost of a high animal density traffic area based on a geotextile-gravel pad construction is approximately one-third (US$ 17 m^{-2}) of that of a concrete area in Sweden.

5. Conclusions

The coarse gravel surface layer reduced runoff flow and the drain flow generated was stable throughout the experiments, confirming pad stability. Almost all response parameters measured in runoff from the pad constructions had low values compared with drainage effluent and leachate.

Manure removal did not have an effect on nutrient content in runoff, but lowered the nutrient content of both drainage effluent and leachate. In the drainage effluent, manure removal lowered the concentrations of TN, TP, COD and TS. A treatment effect was found in the drainage effluent on NO_2-N and TS, with treatment 'Non-woven under' having the best oxidising effect on NO_2-N during both manure removal and accumulation, and 'Non-woven above' having the best trapping effect on TS during manure accumulation. The NO_2-N level in drainage effluent was twice the drinkable water norm according to Swedish Standards (0.5 mg l^{-1}). The entrapment of TS would be beneficial in reducing clogging before treating the effluent in constructed wetland.

The reduction of leachate concentration was primarily an affect of manure removal for most parameters as well as by an overall decrease of sepage rate for all treatments. Manure removal lowered the concentrations of TN, NO_3-N, NO_2-N, TP and TS. The level of NO_3-N developed in this study was 0.13-0.53 mg l^{-1} which resulted in a nutrient content of 0.6-1.5 mg m^{-2}. A treatment response was found for NO_3-N in the 'Non-woven under' and 'Non-woven above' geotextile pads and for leachate COD in 'Non-woven under' and 'Single'. The leakage NO_2-N exceeded the Swedish drinkable water norm in periods. For treatment 'Non-woven under' the nitrogen seepage rate was 0.6 and 0.5 g m^{-2} d^{-1} in manure removal and manure accumulation respectively, which is equal to or below the required norm of 0.6 g m^{-2} d^{-1} for a sealed liner stated by North American Environmental Authorities. The nutrient content of the manure used on the geotextile gravel pads conformed to Scandinavian standards for beef cattle.

The results show that combined geotextile-gravel pad constructions not only have a supporting and draining function in outdoor high density livestock traffic areas, but also a filtering, oxidating and sealing effect, which could be produced by combining the 'Non-woven under' plus 'Single' and 'Non-woven above' geotextiles.

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