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Bedding and Manure Management in Horse Stables

Its Effect on Stable Air Quality, Paddock Hygiene and the Compostability and Utilization of Manure

Doctoral dissertation

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ABSTRACT

The aim of the present study was to observe bedding and horse manure management with regard to its effect on the stable air quality and the environmental impact of a horse establishment over the life cycle of bedding use.

Ammonia adsorption, water absorption, microbial quality and dustiness of different bedding materials and their effect on stable hygiene and manure composting in storage were studied. This thesis also includes preliminary work on the fertilization use of composted horse manure with peat bedding in the organic cultivation of some vegetables. The use of peat for bedding was given special attention in order to examine its potential as horse bedding. In addition, the importance of excreta removal from the horse paddock was studied.

Peat moss was found to adsorb ammonia and hold water better than the other bedding materials studied. Also, the relative content of soluble nitrogen was higher in composted horse manure with peat bedding than in the other composted bedding manure. The ammonia adsorption and water absorption capacity and relative content of soluble nitrogen in composted manure were at least 50% higher in peat than in wood shavings. Temperature development in the compost mass was similar in manure with peat, wood shavings, hemp, shredded newspaper, peat/wood shavings, peat/sawdust and peat/straw.

There was a significant difference between the peat materials in their hygiene quality and dustiness. The geometric mean of fungal number was smallest in light, weakly decomposed sphagnum peat, which, however, contained more endotoxin than the other peat materials. Warming up increased the number of fungi in sphagnum peat but reduced the endotoxin content significantly. Few-flowered peat materials contained thermophilic actinomycetes including *Aspergillus fumigatus*. The concentrations of inhalable and respirable dust and the number of particles were smaller in the few-flowered peat materials than in the sphagnum peat materials.

Composted horse manure with peat bedding was found to be a suitable fertilizer for the organic greenhouse cultivation of tomatoes, sweet peppers and cucumbers. The nutrients from composted horse manure were available for plants longer than those from the control fertilizers. Nitrate concentrations were very low in all the vegetables studied. The hygiene quality of vegetables fertilized with composted horse manure was excellent.

The daily removal of excreta from an unpaved outdoor paddock greatly reduced the nutrient and microbe content in the surface run-off compared with no removal. However, the feeding and drinking places of horses became contaminated both with and without daily removal of excreta.

Bedding material may contain a lot of harmful microbes and organic dust, which is not a desirable property with regard to the health of horses and stable workers. Thus, special attention should be paid to the development of dustless bedding. Further research and practical instruction is required to increase the fertilization use of horse manure. Regular dung removal from the horse paddocks is needed for environmental control.

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CAB Thesaurus: animal housing; stables; horses; bedding; paddocks; horse manure; environmental impact; air quality; composting; peat; actinomycetales; endotoxins; fungi; dust; runoff water; nutrients; phosphorus; nitrogen; fertilization; organic farming

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Sanna Airaksinen

ABBREVIATIONS AND DEFINITIONS

Actinomycete	Actinomycete is a gram-positive bacterium that is able to produce mycelium and spores.
CFU	Number of colony forming units.
C/N-ratio	Ratio of carbon and nitrogen content in the material.
COD	Chemical oxygen demand.
Dung	Solid excreta from farm animal, without bedding.
Endotoxin	Lipopolysaccharide containing parts of cell walls of gram-negative bacteria, which have been found to cause constriction of the bronchus and asthma.
Faecal	Of or relating to faeces.
Few-flowered sedge peat	A type of soil consisting of decaying *Carex pauciflora* plants.
HPLC	High pressure liquid chromatography.
Inhalable dust	Dust particles in size ≤ 10 µm.
Manure	Solid waste from farm animals, mixed with bedding.
Mesophilic	Relating to microbes thriving at room temperature or cooler. The used cultivation temperature in microbe analysis is +25°C.
PFU	Number of plaque forming units.
Respirable dust	Dust particles in size ≤ 5 µm.
Sphagnum peat	A type of soil consisting of decaying *Sphagnum* plants.
Thermophilic	Relating to microbes thriving in temperatures distinctly higher than room temperature. Cultivation temperature used in microbe analysis is +55°C.
Thermotolerant	Heat-resistant microbe. The used cultivation temperature in microbe analysis is +40°C.
Von Post (H 1-10)	Classification of decomposition grade of sphagnum peat (Laine & Vasander, 1990). H 1 is non-decomposed and H 10 is totally decomposed.
Wood shavings	Wood chips in referred article I.

LIST OF ORIGINAL PUBLICATIONS

This dissertation is mainly based on data presented in the following four articles. In the text, these articles are referred to by their Roman numerals:

I Airaksinen S., Heinonen-Tanski H., Heiskanen M.-L.: Quality of different bedding materials and their influence on the compostability of horse manure.
Journal of Equine Veterinary Science 2001, 21: 125-130.

II Airaksinen S., Heiskanen M.-L., Heinonen-Tanski H., Laitinen J., Laitinen S., Linnainmaa M., Rautiala S.: Variety in dustiness and hygiene quality of peat bedding.
Annals Agricultural and Environmental Medicine 2005, 12: 53-59.

III Holopainen P., Airaksinen S., Heinonen-Tanski H., Heiskanen M.-L.: Utilization of composted horse manure with peat bedding in greenhouse and field cultivation.
In: Schmilewski G., Rochefort L. (Eds.): Peat In Horticulture – Quality and Environmental Challenges. Proceedings of the International Peat Symposium, Pärnu, Estonia 3-6 September 2002, 154-160.

IV Airaksinen S., Heiskanen M.-L., Heinonen-Tanski H.: Cleaning of horse paddocks reduces nutrient and micro-organism content in the surface waters.
Bioresource Technology (Submitted)

Additional unpublished data are also included in the thesis.

CONTENTS

1 INTRODUCTION

In Europe, a large number of horse stables are now located in urban areas. For example, in Sweden, 3/4 of horses and 2/3 of stables are situated in urban areas or near cities (Statistics Sweden, 2005). International trends indicate that in Finland, too, an increasing number of stables and horses (61,000; Suomen Hippos ry, 2005) will be situated near cities. The new urbanization of horse establishments has led to international interest in the environmental effects of horse stables' manure management. Today, taking care of environmental matters is necessary for the social approval of stable activity.

There have been difficulties in manure disposal especially in horse stables with no farmland and no external recipient for manure. Horse manure with bedding is classified as bio-waste in the EU and it should be utilized primarily for fertilization and secondly for energy use. Since 1 January 2005, horse manure dumping in landfills has been prohibited in Finland (Council of State Decision No. 861/1997). Manure combustion is possible only at a plant with a licence for waste combustion (Government Decree No. 362/2003). In order to minimize the volume of manure, it is an advantage if bedding material absorbs liquid well and decomposes quickly during manure storage.

Bedding is used for keeping horses clean and for reducing the content of manure gases (e.g. ammonia gas) in the stable's indoor air. The horse is long-lived compared to other agricultural animals and its athletic ability is closely linked to its respiratory well-being. The ammonia adsorption capacity, dustiness and microbial quality of bedding material affect the quality of stable air and thus the well-being of the horses and stable workers. According to Clarke (1987), along with hay, bedding is a major source of fungal spores in stables. Nowadays, replacing hay with less dusty silage is quite common in the diets of horses. This emphasizes the significance of bedding as the source of dust in stables.

Horse manure management is a topical, interdisciplinary theme of major practical importance. Bedding choice and use and manure management in a horse stable affect both the health of horses and stable workers and the environmental impact of a horse establishment.

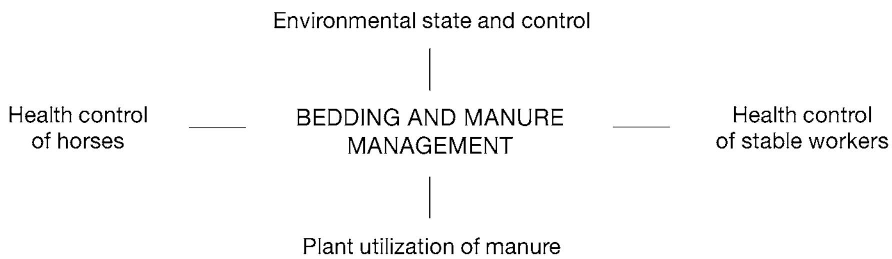

Fig. 1. Effects of bedding (including bedding choice and use) and manure management in a horse stable, taking the main regulations into account.

2 REVIEW OF LITERATURE

2.1 Horse manure management

In the European Union, there are about 4.4 million horses, of which there are approximately 1 million in Germany, 1 million in Great Britain and 0.5 million horses in France (HIEU, 2001). The ratio of horses to people is highest in Denmark and Sweden (HIEU, 2001). The total number of horses is about 175,000 in Denmark (32 horses/1,000 inhabitants) (Statistics Denmark, 2005) and 280,000 in Sweden (31 horses/1,000 inhabitants) (Statistics Sweden, 2005). The number of registered horses is about 61,000 in Finland, which means about 12 horses per 1,000 inhabitants (Suomen Hippos ry, 2005; Statistics Finland, 2005).

Fifteen years ago, in 1991, cattle produced about 80% and horses about 3% of the total quantity of annual manure in Finland (Kapuinen, 1994). During the last decade (1995 – 2004), the number of cattle has decreased by about 16% (Information Centre of the Ministry of Agriculture and Forestry, 2004 and 2005), while the number of registered horses has increased by about 22% (Suomen Hippos ry, 2005). In 2004, Finnish horses produced approximately the same amount of faeces as pigs, and the same amount of total phosphorus and total nitrogen as pigs (weight ≥ 50 kg) and hens (age ≥ 20 weeks) in Finland (Tab. 1). Annual production of faeces and nutrients was estimated for 61,000 adult horses in Table 1, even though ponies and foals (18% of registered horses) may produce only about half the faeces produced by middle-sized, adult horses. Basing the estimate on 61,000 horses is justified on the assumption that the total number of horses in Finland might be higher than the number of registered horses (Heiskanen et al., 2002).

Problems in manure management are often connected with both the urban location of stables with many horses and the use of wood bedding. In Finland, about 50% (Information Centre of the Ministry of Agriculture and Forestry, 2004; Suomen Hippos ry, 2005), and in Sweden, about 25% (Statistics Sweden, 2005) of horses still live on farms. The corresponding figure for Denmark is about 40% (Statistics Denmark, 2005). In Finland, there are about 3,000 stables with ≥ 6 horses, including about 1,000 stables with ≥ 10 horses, and many of them are situated in urban areas (Heiskanen et al., 2002). In Sweden, about 67% of stables are located in or near cities (Statistics Sweden, 2005). Given European trends, it is expected that in future there will be still more stables and horses near cities in Finland, too.

Table 1. The annual production of faeces and nutrients by horses, cows, pigs (weight ≥ 50 kg) and hens (age ≥ 20 weeks) in Finland in 2004. The estimates of the manure and nutrient production are based on the summary of values from Kemppainen (1983), Hubbard et al. (2004) and Phillipp (2004). *: The proportion of urine is about 20% of the total amount of faecal excreta (Hubbard et al., 2004). A: Suomen Hippos ry, 2005. B: Information Centre of the Ministry of Agriculture and Forestry, 2005.

	Horse	Cow	Pig	Hen
Faeces, 1,000 kg/animal/year	8.3 – 9.4 *	14 – 20	0.8 – 1.8	0.06
Number of animals, 1000s	61 A	324 B	441 B	3,069 B
Total amount of faeces, 10^9 kg/year	0.5 – 0.6	4.5 – 6.5	0.4 – 0.8	0.2
Production of P, kg/animal/year	10 – 12	12 – 22	2 – 2.5	0.2 – 0.3
Production of N, kg/animal/year	49 – 65	75 –104	5.6 – 8.0	0.8 – 1.0
Total P, 10^6 kg/year	0.6 – 0.7	3.9 – 7.1	0.9 – 1.1	0.6 – 0.9
Total N, 10^6 kg/year	3.0 – 4.0	24 – 34	2.5 – 3.5	2.4 – 3.0

2.1.1 Manure composting and utilization

Manure from horses is usually drier and contains more bedding material when compared to manure from cattle and pigs. The volumetric content of bedding may be even 60 – 80% in horse manure. Estimates of the mean content of dry matter and nutrients in some domestic animal manure and bedding materials are shown in Table 2.

The most common handling method used for horse manure in Finland is passive composting during storage (Airaksinen, 2000). The main purposes of manure composting are: destruction of pathogens and rubbish heap seeds in the manure (Steineck et al., 2000), and decomposition of bedding (Tiquia & Tam, 2000). Destruction of pathogens is important, especially if manure is used as fertilizer in plant cultivation. According to Solomon et al. (2002), the edible portions of a plant can become contaminated not only through direct exposure to a pathogen but also through transport of a pathogen into the plant by the root system. Spreading of raw manure with a lot of straw or sawdust may lead to a yield reduction especially if the nitrogen needed for the decomposing process of bedding is taken from the soil (Kemppainen, 1983). Swinker et al. (1997) found that two months was too short a time for horse manure composting when shredded phone book paper, sawdust or straw were used as bedding.

Water content, C/N-ratio, concentration of oxygen, temperature and pH are factors that influence the microbial activity of composted material. For optimal decomposition of material, the water content of the mass should be 50 – 60% and the C/N-ratio 20:1 – 40:1 (Swinker et al., 1997). Nitrogen is needed for protein synthesis of microbes active in the decomposing process. The C/N-ratio of horse manure (30:1) (Northeast Regional Agricultural Service, 1992) is at the optimal level for material decomposition (Table 3). Huang et al. (2004) found that temperature development was poorer in pig manure compost with a C/N-ratio of 15:1 than that in pig manure compost with a C/N-ratio of 30:1. The respiration rate of decomposing microbes decreased strongly during composting of food waste at +46°C with a pH below 6.0, compared to composts with a higher pH or lower temperature (Sundberg et al., 2004).

Moncol (1996) found that even 80% of strongyle ovae were destroyed in the manure compost after 24 hours of composting at +40.7°C. Most of the pathogens will be destroyed at a composting temperature of over +55°C in three days (Jones & Martin, 2003). Plant material may protect plant pathogens against the effects of environmental temperature (Veijalainen et al., 2005). In the study of Karlsson and Torstensson (2003), temperatures of almost +60°C were recorded during the first days of the composting

Table 2. Estimates of the mean content of dry matter and nutrients in Finnish manure from horses, cattle, pigs and hens (The Soil Analysis Service, 2000) as well as in straw, peat and wood chip bedding (Kapuinen, 1996).

Material	Content of dry matter, %	Content, kg/1,000 kg material in fresh weight basis			
		Total N	Soluble N	Total P	K
Horse manure	27.0	4.6	0.6	0.9	3.1
Cattle manure	18.4	4.6	1.3	1.3	3.6
Pig manure	23.0	7.2	1.7	3.1	3.7
Hen manure	38.2	15.6	12.8	10.5	11.3
Wheat straw	95.0	4.5	1.0	0.5	14.0
Peat	43.0	3.4	0.3	0.1	0.1
Wood chips (in size 15 mm)	96.0	3.0	0.3	0.3	1.0

Table 3. Mean C/N-ratio of some materials mentioned in the literature ([1]Kirchmann, 1985; [2]Northeast Regional Agricultural Service, 1992; [3]Kapuinen, 1996; [4]Ranneklev & Gislerød, 2002).

Material	C/N-ratio	Material	C/N-ratio
Pig manure	14:1 [2]	Peat	50 – 91:1 [1,3,4]
Sheep manure	16:1 [2]	Sawdust	442:1 [2]
Hay	24:1 [2]	Wood shavings	600:1 [2]
Horse manure	30:1 [2]	Paper	700:1 [2]
Straw	80:1 [2,3]		

period in windrow composting of horse manure. However, there have been differences in the temperature development of horse manure compost with different bedding materials (Moncol, 1996; Swinker et al., 1997).

According to Hammar (2001), the most economic way to utilize horse manure is to spread the manure on the field straight after storage. Manure is characterized as slow-acting fertilizer with soil improvement effect and it could be used to fertilize late-ripening plants like potatoes, root vegetables and grass (Kemppainen, 1983). Karinen et al. (2005) have reported that horse manure with peat bedding is an excellent fertilizer, especially for outdoor cucumbers and carrots when cultivated in clay soils. However, in many cases, manure with wood bedding has been transported to landfills because there was no fertilization value in this kind of manure (Airaksinen & Heiskanen, 2004). Composting causes nitrogen losses in manure (Tiquia & Tam, 2000). Steineck et al. (2000) recommend the addition of mineral nitrogen when horse manure is spread on the field.

2.1.2 Regulations

Manure management of animal houses is regulated by the Government Decree on the Restriction of Discharge of Nitrates From Agriculture into Waters (No. 931/2000) in accordance with the Council of the European Communities Directive 91/676/EEC of 12 December 1991 "concerning the protection of waters against pollution caused by nitrates from agricultural sources". This Government Decree is based on section 11 of the Environmental Protection Act (86/2000) and includes both regulations and recommendations regarding manure storage and spreading, and guidance for good farm management. According to this Decree, the main requirements for manure storage are:

1. Manure storages must be watertight.
2. Storage capacity must be sufficiently large for manure accumulated over 12 months, excluding manure remaining on pasture during the same grazing season. The recommended capacity for 12-month storage is 12 m^3 for a horse and 8 m^3 for a pony (Finnish Ministry of Agriculture and Forestry, 1996).
3. Loose housing sheds with litter bedding are also considered in determining the size of storage.
4. Manure storage in heaps is permitted only in exceptional cases.

Horse manure storage and spreading is also controlled by the Waste Act (No. 1072/1993) and Regulation (EC) No 1774/2002 of the European Parliament and of the Council of 3 October 2002 laying down health rules concerning animal by-products not intended for human consumption. According to Section 6 of the Waste Act (1993), priority shall be given first to recovery of the material contained in waste and second to recovery of the energy contained in waste. In that way, horse manure should be exploited primarily as a fertilizer in plant cultivation. According to the Council of State Decision No. 861/1997, the dumping of manure in landfills has been prohibited since 2005.

Table 4. The principal regulations governing manure management in horse stables in Finland.

Year	Regulation	Aim of regulation
1991	Council Directive of 12 December 1991 concerning the protection of waters against pollution caused by nitrates from agricultural sources (91/676/EEC)	Manure storage and spreading
1993	Fertilizer Act (No. 232/1993)	Manure management before selling it as a fertilizer
1993	Waste Act (No. 1072/1993)	Manure storage, handling and spreading
1997	Council on State Decision (No. 861/1997)	Manure transportation into the landfilling
2000	Environmental Protection Act (No. 86/2000)	Environmental permit
2000	Environmental Protection Decree (No. 169/2000)	Environmental permit
2000	Government Decree on the Restriction of Discharge of Nitrates From Agriculture into Waters (No. 931/2000)	Manure storage and spreading
2002	Regulation (EC) No 1774/2002 of the European Parliament and of the Council of 3 October 2002 laying down health rules concerning animal by-products not intended for human consumption	Manure handling, transportation and exploitation
2003	Government Decree on the Combustion of Waste (No. 362/2003)	Manure combustion

Combustion of manure is permitted only at a plant with a licence for waste combustion (Government Decree on the Combustion of Waste, No. 362/2003).

An environmental permit granted by a regional environmental centre is needed for professional handling of horse manure (Environmental Protection Act, No. 86/2000, Section 28; Environmental Protection Decree, No. 169/2000, Section 1). Horse manure with no composting or decaying treatment may be given to a compost producer only if the transportation and documentation requirements stated in Regulation (EC) No 1774/2002 of the European Parliament and of the Council of 3 October 2002 are followed. The Fertilizer Act (No. 232/1993) applies to horse manure that has been processed technically for selling.

According to Section 19 of the Environmental Protection Act (No. 86/2000), municipal councils may, on the basis of local circumstances, issue general regulations pertaining to manure removal from horse paddocks. A stable owner must inform the environmental authority of his municipality if the 12-month manure storage is replaced partly or totally with manure transport to another farmer or compost producer (Government Decree No. 931/2000, Section 4). The Finnish Ministry of the Environment (2003) has published instructions concerning environmental protection in horse stables. The purpose of these instructions was to standardise the interpretation of regulations in Finland.

2.2 Effects of bedding and manure management

2.2.1 Health effects on stable workers and horses

Farm workers' exposure to unhealthy factors like ammonia gas, organic dust and biological aerosols has been the subject of several studies (Kotimaa et al., 1984; Kotimaa, 1990a & b;

Eduard, 1997; Louhelainen et al., 1997; Hanhela, 1999; Lappalainen, 2002; Rautiala et al., 2003). Bedding is known to be a major source of fungal spores, along with hay, in the stable (Clarke, 1987), and, for example, straw bedding has been found to increase cowmen's exposure to dust and microbes significantly (Hanhela, 1999). According to Kotimaa (1990b), patients with farmer's lung are exposed to higher concentrations of spores originating from xerophilic, mesophilic and thermotolerant fungi and thermophilic actinomycetes than their healthy siblings in farm work. Ammonia concentration in a stable's indoor air is associated with the quality and quantity of bedding material used (Raymond et al., 1994b), manure handling (Woods et al., 1993; Raymond et al., 1994a; Louhelainen et al., 1997) and the individual character and activity of the animals (Lawrence et al., 1988).

The horse is a long-lived animal compared to other agricultural animals and its athletic ability is closely linked to its respiratory well-being. According to Holcombe et al. (2001), stabling is associated with inflammation of both the upper and lower airways of young horses. Horses suffering from chronic bronchitis are more often sensitized to *Aspergillus fumigatus* and *Alternaria alternata* allergens than horses in the control group, and they are partly sensitized to the same fungal proteins as mould-allergic human patients (Eder et al., 2000). According to Pirie et al. (2003), inhaled endotoxin also contributes significantly to the induction of airway inflammation and dysfunction in horses. The concentration of biologically-active endotoxin has been reported to be associated quite closely with workers' reported symptoms (Laitinen et al., 2001). Workers' respiratory symptoms have been reported to increase when the endotoxin content of the air is >250 EU (endotoxin unit)/m^3 (Laitinen, 1999). The Dutch Expert Committee on Occupational Standards (Heederik & Douwes, 1997) has recommended a health-based occupational exposure limit of 50 EU/m^3 over an eight-hour period of endotoxin exposure.

2.2.2 Environmental effects

Uncontrolled spreading of horse manure nutrients into the environment is possible through manure transportation, poor storage and from paddocks. Some of the nitrogen will be lost during manure composting (Kemppainen, 1983; Tiquia & Tam, 2000), but composting has not been found to have an effect on the phosphorus concentration of manure (Preusch et al., 2002). According to Karlsson and Torstensson (2003), release of ammonia appears to be most effective during the first week of horse manure composting. In windrow composting of horse manure, ammonia emissions were measured at 0.3 – 0.4 kg NH_3-N per tonne of manure, corresponding to a 6 – 8% loss of initial total nitrogen content (Karlsson & Torstensson, 2003). The results of He et al. (2001) in laboratory scale composts showed that N_20 was produced mainly (95%) during the later period of composting when carbon sources had been depleted.

Nutrient leaching from horse manure storage has been found to be unlikely because of the high dry matter content of manure (Puumala & Sarin, 2000). However, in the study by Karlsson and Torstensson (2003), the total nitrogen concentrations in leaching water from the composting pad of horse manure periodically reached levels of 160 mg/l in conditions with high loads of manure and precipitation. In this Swedish study, the concentrations of phosphorus were also very high at between 2 – 67 mg/l (Karlsson & Torstensson, 2003). Parkinson et al. (2004) found that there was a close relationship between increasing nutrient losses in both leachate and gaseous forms of nitrogen and increased turning frequency of composted manure.

Studies concerning the effects of horse paddocks on water have been quite rare so far. However, according to Närvänen et al. (2001), the concentration of soluble phosphorus in surface run-off water from a sand-based horse paddock was 30-fold when compared to water from agricultural land. The environmental effects of cattle grazing and breeding cattle outdoors have been studied somewhat both in Finland and in other countries. Run-off water from cattle grasslands (Hunter et al., 1999; Hooda et al., 2000; Crowther et al., 2002) and winter pens (Uusi-Kämppä et al., 2003) has been found to contain remarkable amounts of nutrients and faecal microbes. Watersheds with concentrated livestock populations have been shown to discharge as much as 5 – 10 times more nutrients than watersheds in cropland or forestry land (Hubbard et al., 2004). Most of the total nitrogen measured in the run-off from cattle pens has been in the form of ammonia-nitrogen and the concentration of nitrogen has been low (Uusi-Kämppä et al., 2003). Concentrations of nutrients have been significantly higher in the run-off water from winter pens than the concentrations found in Finnish lakes and rivers (Table 5).

Vegetation and the gradient of the land, stock density and weather conditions affect the quality of surface run-off from agriculture (Stout et al., 2000). It is likely that paddock management and the base material affect the nutrient content of surface run-off waters from a horse paddock, as was found in studies with cattle (Uusi-Kämppä, 2002; Uusi-Kämppä et al., 2003). According to Saarijärvi et al. (2004), cutting and grazing did not represent a risk to groundwater quality during grass cover years, but renovation of pasture with herbicide treatment in autumn caused a significant leaching of nitrogen into groundwater.

According to Jansson et al. (2002), phosphorus usually accumulates in the surface layer of soil. Thus, fertility analysis may be used for phosphorus load assessment in soil (Jansson & Tuhkanen, 2003). Removal of the surface layer from the exercise area and dung from the feeding area will reduce water loading (Uusi-Kämppä, 2002; Jansson & Tuhkanen 2003). According to Puumala et al. (2003), COD concentration was reduced on average by about 93%, total nitrogen by 43 – 61% and total phosphorus by less than 40% when mixtures of straw/peat and straw/wood chips were used for the exercise area's wastewater treatment compared to the plain exercise areas. According to the review by Knowlton et al. (2004), reducing the overfeeding of animals is a powerful approach to reducing phosphorus losses from livestock farms.

2.3 Quality of different bedding materials

Bedding materials may be classified into two groups: plant materials including straw, hemp, linen and peat; wood materials including wood shavings, sawdust and shredded paper. From a practical point of view, water absorption capacity, ammonia adsorption capacity and hygiene quality can be seen as important properties in bedding. Choice of bedding is also related to price, availability and visual appearance.

The use of straw for bedding is worldwide and especially in areas of cereal cultivation. Straw may be the most common bedding in Central Europe and in the southern parts of the Nordic countries. The use of wood shavings for

Table 5. Mean concentration of total phosphorus, total nitrogen and soluble phosphorus in the biggest rivers and lakes in Finland calculated from the data for 1975 – 2000 (Räike et al., 2003) and in the run-off water from cattle pens (Uusi-Kämppä et al., 2001; Uusi-Kämppä et al., 2003).

Nutrient	Concentration in rivers, (µg/l)		Concentration in lakes, (µg/l)	Concentration in run-off water from animal pens, (µg/l)
	Mean	Range	Mean	Range
Total phosphorus	61.5	(10 – 150)	17	1,700 – 120,000
Total nitrogen	999	(340 – 3,200)	390	30,000 – 350,000
Soluble phosphorus	28.6	(0.5 – 84)	1.8	1,400 – 38,200

bedding is also international, and it is a popular material especially in the Nordic countries. Linen and hemp are produced and used as bedding to some extent in Central Europe.

The use of peat for bedding is not entirely accepted in Central Europe because of its characterization there as a non-renewable natural resource. In Finland and Sweden, peat is regarded as a slowly-renewing natural resource with multiple uses and its use for bedding has been quite common. According to Selin (1999), the use of peat in Finland can be considered sustainable because more peat is accumulating annually (15.4 million tonnes CO_2) than is being utilized. Weakly decomposed sphagnum peat (von Post H 1-3), collected from the surface layer of a bog and yielded as side product in fuel peat production, has been found to be a suitable bedding material for farm animals (Peltola et al., 1986).

2.3.1 Liquid absorption and ammonia adsorption capacity

The liquid absorption capacity of bedding (Table 6) affects the daily consumption of bedding and the amount of manure with dirty bedding needing to be handled. According to Ward et al. (2000), shredded paper pellets and wood shavings absorbed twice as much water as that absorbed by straw. However, there are differences between bedding materials in their capacity to absorb water and urine. According to Peltola et al. (1986), peat absorbed urine 8% better than water but straw absorbed water 28% better than urine. A rise in water content from 10% to 70% increased the ammonia adsorption capacity of peat by 17%, of straw and wood shavings by more than 20% and of sawdust by 38% (Kemppainen, 1986). According to Särkijärvi et al. (2004), the consumption of peat was 0.5 m^3 and of wood shavings 0.9 m^3 per horse per week.

The importance of the ammonia adsorption capacity of bedding material is high both in summer, when the indoor temperature in the animal house rises (Slobodzian-Ksenicz & Kuczyñski, 2002), and in winter, when the ventilation should be reduced because of the cold weather. Peat moss is an excellent ammonia adsorbent (Kemppainen, 1985) due to the low pH of peat (Jeppsson, 1999). Jeppsson found that a peat/chopped straw mixture (ratio 60%:40%) reduced ammonia emission from the bedding base of bulls by 57% when compared to a bedding of straw.

Shredding has been found to improve the ammonia adsorption capacity of long straw (Kemppainen, 1985; Jeppsson, 1999). According to Slobodzian-Ksenicz and Kuczyñski (2002), ammonia emission was higher with long straw (40 – 70 cm) than with chopped straw (5 – 8 cm) or wood shavings during the first 7 – 8 weeks of their study of bedding bases for turkeys. The ammonia adsorption capacity of straw can also be improved by daily addition of an ammonia adsorbent like sodium bisulfate (Sweeney et al., 1996) or a paper pulp product (Raymond et al., 1994a).

Table 6. Reference values for the liquid absorption (Vahala, 1982; Peltola et al., 1986; Häussermann et al., 2002) and ammonia adsorption capacity of some bedding materials (Vahala, 1982; Kemppainen, 1985).

Material	Water absorption capacity, kg H_2O per kg dry matter (DM)	Liquid absorption capacity, kg liquid per kg bedding material	Ammonia adsorption capacity, % from dry matter
Peat	7.5 – 12.0	4.9	1.0 – 2.5
Hemp	No data	3.2	No data
Straw	3.3	2.5 – 3.0	0.5 – 0.85
Wood shavings	4.6	2.4 – 3.3	0.8
Sawdust	1.9	1.5	0.2 – 0.5

2.3.2 Microbial quality and dustiness

The microbial quality and dust content of bedding materials have been mostly studied by taking air samples from animal houses with different bedding (Tables 7 and 8). Comparison of the results of indoor air studies is quite difficult because of the differences in animal activity, ventilation and other circumstances. The rotating drum method has been used in studies of the dustiness of chopped straw (Breum et al., 1999) and bedding used for laboratory animals (Kaliste et al., 2004). The microbial quality of straw, peat and wood shavings has also been studied by means of material samples (Table 9). Studies of the microbial quality and dustiness of hemp and linen are not known to the writer.

Along with hay, straw is considered to be a major source of fungal spores in the stable (Clarke, 1987), although, according to Webster et al. (1987), well-managed bedding revealed only small differences between straw, wood shavings and paper, and in these circumstances hay tended to be the major source of respirable spores. Woods et al. (1993) noticed that concentrations of respirable and total dust in stable air were significantly lower in a recommended environment utilizing wood shaving bedding and a complete pelleted diet

Table 7. Some reference values for the dust concentration in the indoor air of animal houses during dirty bedding removal.

	Straw	Peat	Paper	Wood shavings
Inhalable dust, mg/m^3	2.60 [2]	7.5 (DM 54%) [5]	No data	0.70 [2]
Respirable dust, mg/m^3	0.40 [2]	No data	No data	0.20 [2]
Respirable dust, number of particles in litre of air	12,000 – 76,000 [1, 3, 4]	No data	15,000 – 40,000 [1, 3]	31,000 [1, 4]

[1]Webster et al., 1987 (particle size 0.5 – 5 µm). [2]Woods et al., 1993. [3]Raymond et al., 1994b. [4]Vandenput et al., 1997. [5]Mäittälä et al. 2001.

Table 8. Some reference values for the concentration of microbes, endotoxin, fungal spores and dust in the indoor air of animal houses measured during dirty bedding removal.

	Straw	Peat	Paper	Wood shavings	Sawdust
Total content of microbes x 10^4, CFU/m^3	370 [1]	160 [6]	No data	No data	21 [6]
Number of gram-negative bacteria x 10^3, CFU/m^3	No data	110 [6]	No data	No data	15 [6]
Content of endotoxin x 10^2, EU/m^3	0.4 – 140 [2, 5]	32 – 310 (DM 54%) [3]	0.20 [2]	No data	0.2 – 270 [2, 3, 5]
Number of thermophilic actinomycetes x 10^2, CFU/m^3	6700 [1]	51 [6]	No data	No data	0.3 [6]
Number of mesophilic fungi x 10^2, CFU/m^3	19000 [1]	38 – 360 [4, 6]	No data	10 [4]	20 [6]
Number of thermotolerant fungi x 10^2, CFU/m^3	2300 [1]	220 [6]	No data	No data	1.7 [6]

[1]Kotimaa, 1990a. [2]Tanner et al., 1998. [3]Mäittälä et al., 2001. [4]Lappalainen, 2002. [5]Rieger et al., 2002. [6]Rautiala et al., 2003.

Table 9. Summary of the microbial quality of different bedding materials.

	Peat	Straw	Wood shavings
Mesophilic fungi, CFU/g	$10^2 – 10^8$ [3,4]	$10^4 – 10^6$ [3]	10^3 [4]
Thermotolerant fungi, CFU/g	$10^3 – 10^5$ [3]	$10^2 – 10^4$ [3]	No data
Thermophilic actinomycetes, CFU/g	$10^2 – 10^3$ [3]	$10^2 – 10^4$ [3]	10^2 [4]
The fungi reported to occur in at least 50% of the bedding samples	*Penicillium*, yeast, *Paecilomyces* [2,3]	*Cladosporium*, *Penicillium*, yeast, sterile fungi, *Fusarium* [2,3]	*Penicillium*, *Aspergillus glaucus*, yeast [1]
The actinomycetes reported to occur in at least 50% of the bedding samples		*Thermoactinomyces Candidus*, *Thermoactinomyces vulgaris* [2,3]	

[1]Kotimaa et al., 1991. [2]Hanhela et al., 1995. [3]Mäittälä et al., 2001. [4]Lappalainen, 2002.

than in conventional management utilizing hay feed and straw bedding. In the study by Tanner et al. (1998), straw stalls had higher levels of airborne endotoxin as compared to the phone book paper and sawdust stalls. However, gram-negative bacteria and fungi were prevalent in the air of all the stalls (Tanner et al., 1998). In the study by Vandenput et al. (1997), good-quality straw was significantly less dusty with fewer allergens than wood shavings, and the content of respirable dust was lower in wood shavings than in good hay. According to Rieger et al. (2002), the endotoxin content in horse stable air varied: 2,000 EU/m^3 in stables with sawdust bedding, 14,000 EU/m^3 in stables with straw bedding, and 22,000 EU/m^3 in stables with hemp bedding.

According to Särkijärvi et al. (2004), the weight of total dust was similar in horse stables bedded with peat and wood shavings. However, problems due to the dustiness of peat with high content of inhalable dust and microbes (fungi, bacteria) in the workplace have been reported (Mäittälä et al., 2001). Larsson et al. (1999) have suggested that a water content of 50% would keep the dust content of the air low enough during peat bedding handling. Rautiala et al. (2003) reported that mesophilic *Penicillium* and yeast were common also in air samples in composting swine confinement buildings using peat as composting bedding. Clarke and Madelin (1987) found *Aspergillus candidus* and *Streptomyces* species in clean peat bedding.

The microbial quality of straw (Kotimaa, 1990a; Kotimaa et al., 1991), wood shavings (Kotimaa et al., 1991; Airaksinen, 2004) and peat (Ranneklev & Gislerød, 2001) has been found to depend on the method of storing. The number of microbes liberated from straw decreased sharply in midwinter but increased again in the late spring (Kotimaa et al., 1991). Thus, special attention should be paid to reducing the moisture content of straw before storing in order to lower the risk of moulding (Kotimaa, 1990a). Self-heating of peat during storage in stockpiles has been found to increase the micro-organism content of peat significantly compared to unheated peat (Ranneklev & Gislerød, 2001).

2.3.3 Costs

The total cost of bedding management comprises the price of bedding material (EUR/m^3), bedding transportation and storage costs, bedding consumption costs, labour costs involved in bedding and manure management, and manure utilization costs. The annual cost of bedding without labour and manure management costs is assumed to be about 100 – 140 EUR per horse

(Airaksinen, 2000; Heiskanen et al., 2002). Thus, the value of horse bedding production in Finland may have been 6.1 – 8.5 million EUR in 2004. There is a lot of variation in the total cost of bedding management owing to the different manure management methods. Comprehensive comparison of the cost of bedding and manure management in horse stables has not been done so far.

Plastic packaging may ease the storage of bedding but will also increase the price of the bedding material (EUR/m^3) about fivefold as against bedding without packaging (Table 10). According to information from a Finnish agricultural store, the price of a 30 kg package of Finnish peat was about 8 EUR and the price of a 25 kg package of Finnish wood shavings about 6 EUR in spring 2005. The price of a 20 kg package of foreign hemp bedding was about 18 EUR (Information from a commercial horse equipment store, 2004). Plastic packaging waste from bedding may cause extra expenses to a stable because of the increased payments for waste management.

The price of peat sold either loose or in plastic packaging is about 1½ times the price of wood shavings. Straw has been a slightly cheaper bedding material than peat moss or wood shavings, but it may be difficult to find good-quality straw, especially in areas with no cereal cultivation. So far, there has been no Finnish linen or hemp bedding for sale in Finland.

Table 10. Estimates of the prices in 2005 and use of some bedding materials in Finland. Transport costs are not included in the following prices. (Airaksinen, 2000; information provided by stable entrepreneurs and bedding suppliers, 2005).

Material		Price, EUR/m^3	Use in Finland, % (loose material + packaged)
Wood Shavings	loose material	4 – 6	40
	packaged	25	
Sawdust	loose material	4 – 6	27
Peat	loose material	6 – 8	17
	packaged	42	
Straw	loose material	2.3 – 2.8	15
	packaged	10	
Other			1

3 AIMS OF THE PRESENT STUDY

The aim of the present study was to observe bedding and horse manure management with regard to the following: the effect of bedding material and manure management on the indoor environment (hygiene, air quality) and the environmental impact of a horse establishment over the life cycle of bedding use.

This involved studying the properties of different bedding materials and their effect on stable hygiene and manure composting in storage. This study also includes preliminary work on the fertization use of composted horse manure with peat bedding in the organic cultivation of tomatoes, cucumbers and sweet peppers. The use of peat for bedding was given special attention in order to examine its potential as horse bedding. In addition, the importance of horse paddock management as part of integrated stable manure management was studied. The more detailed objectives of the present series of studies were:

- To compare the qualities of different bedding materials and their effect on the compostability of horse manure (I).
- To evaluate the dustiness and microbial quality of peat bedding (II).
- To assess the usability of composted horse manure with peat bedding as a fertilizer in plant cultivation (III).
- To describe how dung removal affects the nutrient and microbe content of surface run-off from horse paddocks (IV).

4 MATERIALS AND METHODS

4.1 Bedding materials in the study (I, II)

The bedding study (I) was conducted in 1998 in a stable with 16 horses. The materials studied were straw, sphagnum peat, hemp, linen, wood shavings, sawdust, shredded newspaper and the following mixtures (3:1): sphagnum peat/wood shavings, sphagnum peat/sawdust, sphagnum peat/straw. The straw used was cut into 10 cm strips for the mixture. The mean volume weight of the materials on fresh basis (g/l) (n=3) was as follows: peat 164 g/l, straw 36 g/l, hemp 108 g/l, linen 182 g/l, wood shavings 98 g/l, sawdust 248 g/l and shredded newspaper 85 g/l. The moisture content of bedding materials was not determined. Apart from the hemp and linen, the bedding materials used were domestic. The same worker took care of the bedding during the study, which was supposed to minimize the removal of clean bedding to compost boxes. Each bedding material was tested with four horses.

The peat moss materials examined in laboratory conditions in 2004 (II) were:

- light, weakly decomposed sphagnum peat (a type of soil consisting of decaying *Sphagnum* plants), von Post H 1-2, DM (dry matter content) 73 – 75%,
- light, weakly decomposed sphagnum peat, warmed up in storage (>30°C), von Post H 1-2, DM 68 – 72%,
- more decomposed few-flowered sedge peat (a type of soil consisting of decaying *Carex pauciflora* plants), von Post H 3-4, DM 56 – 59%, and
- more decomposed few-flowered sedge peat, von Post H 4-5, DM 56 – 59%.

The volume weight on fresh basis (g/l), pH and humidity content (%) of the studied peat materials are presented in II, Table 1.

4.2 Quality of bedding (I, II)

4.2.1 Ammonia adsorption capacity (I)

Ammonia adsorption capacity was measured with Dräger diffusion tubes ($NH_3$20/a-D, Liitin Oy, PO Box 33, 00391 Helsinki, Finland) placed in a plastic bag containing 200 ml of bedding material (measured with loose bedding) and 800 ml of fresh horse urine. Measurement (n=2) was done after two hours' incubation at +17.4°C. Total concentration of ammonia in the plastic bag was measured with 0.8 dl of pure horse urine (n=2). The ammonia adsorption capacity of the bedding material was calculated by the following equation:

$$A = ((T - c/t) : T) \times 100\%,$$ where

A = adsorption capacity of material (%),
T = total concentration of ammonia in a plastic bag with pure horse urine (ppm/h),
c = concentration of ammonia in a plastic bag with bedding material and urine (ppm), and
t = incubation time (h).

4.2.2 Water holding capacity (I)

The water holding capacity of the bedding material was measured in a barrel (diameter 20 cm, height 24 cm) with a strainer bottom (V=10 litres). The barrel was placed on a larger collecting vessel. One litre of bedding material and two litres of water were added to the barrel, and the water passing through the strainer was collected and measured one hour later (n=3). Water was added to the barrel by pouring it from a can. The bedding material was totally wet before straining was started. The measurements were made at room temperature.

4.2.3 Fungi and bacteria (I, II)

The microbial analyses of the bedding materials were done by the Kuopio Regional Institute of Occupational Health (I, n=2. II, n=4). Mesophilic fungi (I, II), xerophilic fungi (I), thermotolerant fungi (I, II), mesophilic bacteria (I) and thermophilic actinomycetes (I, II) were determined from material samples with commonly used growth media. The numbers of colony forming units (CFU) were counted after incubation and identified microscopically.

4.2.4 Dustiness and the endotoxin content of peat (II)

The aim of this procedure was to simulate the dust exposure of workers and horses. Spreading of the dust from the peat material in the cylinder was attempted to simulate the changing bedding in a horse stable. The study was done in the laboratory in order to minimize the effect on the results of external influences, such as ventilation, the external temperature and humidity content, and animal activity.

A one-litre sample was taken and analysed for dustiness using a rotating drum with a cylinder (Fogelmark et al., 1989) 70 cm long and 30 cm in diameter, containing eight mixing plates 5 cm in height. Three air samples were taken from the cylinder on three different filters at the same time, and the number of particles released during rotation was counted. The cylinder was rotated six times at a speed of 34 rpm, for three minutes at a time, at 10-minute intervals.

The sampling time for each filter was 60 minutes, during which the stationary samples for inhalable dust, respirable dust and endotoxin were collected with IOM samplers for 18 minutes. Endotoxin and inhalable dust were sampled with IOM samplers and respirable dust with an IOM sampler provided with polyurethane foam. Dust samples were taken with the use of calibrated pumps (Model 224, SKC, USA) at an airflow of 2.0 litres per minute. The dust was analysed gravimetrically with a method used by the Kuopio Regional Institute of Occupational Health. A filter was stored in a dessicator at least two days before weighing it in a weighing room (20±5°C, RH 45±5%). The scales used were a Mettler Toledo AT261/DR (analytical balance sensitive to 0.01 mg).

The number of dust particles released into the air was counted using an optical particle counter (Hiac/Royco, Model 5000, Spacific Scientific®, USA). The particle counter measured the number of particles of different sizes in five categories: 0.3 – 0.5 µm, 0.5 – 1 µm, 1 – 3 µm, 3 – 5 µm and 5 – 10 µm. The concentration of endotoxins was determined by the kinetic Bio Whittaker-QCL method, based on the LAL (Limulus amebocyte lysate) enzyme. The sampling procedure was performed five times consecutively for each peat material. The cylinder was vacuumed thoroughly after every rotated material.

4.3 Handling and utilization of horse manure (I, III)

4.3.1 Composting and fertilization value of horse manure (I)

The composting study of horse manure with bedding was conducted at the school farm of the Ylä-Savo Vocational Institute in Kiuruvesi (63°39’N, 26°38’E) in summer 1998. The box stalls (each about 9 m^2) were cleaned daily during the bedding study and the produced manure with different bedding materials (m^3) was estimated during mucking out. For a week, faeces and bedding with urine were removed to wooden composting boxes (1 m^3) with a wooden cover by hand with a fork. Removal of clean bedding was avoided. The bedding materials studied were long straw, peat, hemp, wood shavings, shredded newspaper, peat/wood shavings, peat/sawdust, and peat/chopped straw.

After a one-week period of manure collection, measurements of temperatures in the composting mass were started. The temperature was measured once a day for 34 – 35 days. Measurements were taken at depths of 10 cm, 22 cm (n=4) and 30 cm (n=2) from the top of the composting mass.

The collection sample (V=1 litre) for nutrient analysis comprised ten separate random samples and was collected from a depth of 10 – 20 cm from the top of the composting mass on the first day and then three weeks and six weeks after starting the composting study. Soil analyses, determining the total potassium, total phosphorus, soluble nitrogen, dry matter, and bulk density (kg/m^3) of the manure, were done by the Soil Analysis Service (Mikkeli, Finland). The bulk density was measured by filling a 200 ml test cylinder with a sample "as received", static compaction and weighing of the content of the cylinder.

The biological activity in the composting mass, including the number of mould colonies, the formation of fungi and the number of flies, was observed daily. The number and vitality of rubbish heap seeds in the composted manure was studied with a simple germination test, where, after different composting durations (0, 10, 22 and 39 days), manure samples (n=3, V=0.2 litre/sample) were taken to room temperature and watered for ten days.

After 27 – 28 days of composting, the masses were aerated by turning in order to avoid a further decrease in the composting temperature caused by the lack of oxygen or moisture in the mass.

4.3.2 Greenhouse cultivation study (III)

The utilization of composted horse manure with peat bedding as a fertilizer for organic greenhouse cultivation of tomatoes, cucumbers and sweet peppers was studied at the school farm of the North Savo Regional Consortium for Education in Muuruvesi (63°04'N, 28°19'E) during the growing season in 2001. Composted cattle manure and several organic fertilizers served as controls for the composted horse manure with peat bedding in this preliminary study.

The growing medium used in the cultivation of tomatoes, cucumbers and sweet peppers was a limed and organically fertilized peat growing board (length 100 cm, width 26 cm and thickness 13 cm when moistened), whose conductivity was regulated at 3 mS/cm for tomatoes and sweet peppers and 2 mS/cm for cucumbers. The growing boards were placed in double rows and the space volume between two growing board rows (0.02 m^3 per metre) was filled with basic fertilizer (composted horse manure with peat bedding, composted horse manure with peat bedding + Basic Fertilizer for Organic Cultivation + Chicken Manure or composted cattle manure + Basic Fertilizer for Organic Cultivation + Chicken Manure) as presented in III, Tables 1a and 1b.

The application rate of composted horse manure with peat bedding and composted cattle manure was based on the same volume of used manure and was: tot-N 0.84 kg/m^2, tot-P 0.12 kg/m^2 and K 0.35 kg/m^2 with composted horse manure with peat bedding and tot-N 1.86 kg/m^2, tot-P 0.09 kg/m^2 and K 0.57 kg/m^2 with composted cattle manure. The nutrient values (N, P and K) and content of the fertilizers and growing board for organic cultivation used are shown in III, Table 1b. Additional fertilization (Basic Fertilization for Organic Cultivation or Allgrow seaweed extract) was applied to the growing medium by watering with drops. Use of additional fertilization was based on decreasing canopy growth and a lightening in the colour of leaves.

Details of the planting and harvesting period as well as the fertilization and watering of tomatoes, cucumbers and sweet peppers are presented in III, Table 1a. The growth of the vegetables was determined at the end of the growing period.

4.3.3 Quality assessment of vegetables (III)

The nitrate and sugar concentrations and the hygiene quality of the vegetables with different fertilizations were analysed. In addition, the effect of the fertilizers on the taste and other qualities (smell, structure, colour) of the vegetables was studied. The tastes of all test variants of the same plant species were assessed on the same day that the samplings for all the chemical and microbiological analyses were done. Thus, the exact ripening phase may have varied according to possible different growth rates.

The nitrate content of the vegetables was analysed with an ion chromatograph (761 Compact IC). Samples were dissolved in a $CaSO_4$ buffer and determined with a 15 min run/sample. The concentrations of glucose and fructose were measured by HPLC.

The tastes of the vegetables were assessed with the triangle test (Meilgaard et al., 1991) and the ordinal test. In the triangle test, each taster was given three samples, two of which were the same and the other different. The taster was asked to identify the different sample. In the ordinal test, each taster was asked to order samples according to some quality factor (taste, structure). In the case of three different samples, the number of possible sample combinations in the ordinal test was six (ABC, ACB, CBA, CAB, BAC and BCA). The ordinal test was used to support taste assessment by the triangle test.

There were 29 tasters in the group, nine men and 20 women aged between 16 and 58 years. Seventeen of the tasters were under 30 years old (five men and 12 women), and 12 over 30 years old (four men and eight women).

Faecal coliforms, faecal streptococci, faecal clostridium and two coliphages (hosts Escherichia coli ATCC 15597 and ATCC 13706) were used as indicators of faecal contamination.

4.4 Surface water effects of manure management in paddocks (IV)

4.4.1 Experimental design

Study (IV) was done from 1 Oct 2001 – 13 Aug 2002 at the school farm of the Ylä-Savo Vocational Institute in Kiuruvesi (63°39'N, 26°38'E). It was carried out in two similar open stable departments, both with three adult horses. Both departments comprised a sleeping room (A=45 m^2) and a sand-based paddock (A=800 m^2, 267 m^2/horse, thickness of sand base 350 mm). The base materials of the paddocks were replaced before the study. Surface run-off from the paddocks was drained via low open ditches (approximate depth 300 mm) into the collection wells (diameter 600 mm, depth 1500 mm). The location of the collection wells is shown in IV, Fig. 1. The paddock of department A was cleaned of dung daily (with a manure fork and a shovel) and the paddock of department B was left uncleaned. The quantity of dung produced in paddock A was weighed monthly.

The collection wells for surface run-off water in the lower parts of the paddocks were hedged to prevent the horses from walking over the wells. The horses' movements, grooming, feeding, location of defecation and the weather were followed daily. The average length of time that the horses spent outside per day was six hours. The horses were moved to grassland in the middle of May. The surface run-off from the empty paddocks caused by summer rain was determined in the middle of August.

4.4.2 Surface run-off water samples

The surface run-off water samples were subjected to chemical and microbiological analyses. In the chemical analyses, the total phosphorus (SFS-EN 1189, 1997), phosphate (SFS-EN 1189, 1997), total nitrogen (SFS 3031, 1990), nitrate (SFS-EN ISO 13395, 1997), ammonium (Lachat 107061F-method) and potassium (SFS 3017, 1982) content of the water was determined. The indicators of the microbiological quality of the water were: the numbers of culturable micro-organisms (SFS-EN ISO 6222, 1999), enterococci (SFS-EN ISO 7899-2, 2000), faecal coliforms (SFS 4088, 2001), sulphite-reducing clostridia (SFS-EN 26461, 1993) and total numbers of coliforms (SFS 3016, 2001). Sampling dates and precipitation during the study are shown in IV, Fig. 2. The total volume of drainage into the collection wells in the cleaned paddock and the feeding area (upper part) and lower part of the uncleaned paddock on 31 Oct 2001, 6 May 2002 and 13 August 2002 is presented in Table 11.

Table 11. Total volume of drainage in collection wells in the cleaned paddock and the feeding area (upper part) and lower part of the uncleaned paddock on 31 Oct 2001, 6 May 2002 and 13 Aug 2002.

Location of the collection well	Total volume of drainage (l)		
	31 Oct 2005	6 May 2002	13 Aug 2002
Cleaned paddock	133	136	215
Uncleaned paddock, upper part	291	246	331
Uncleaned paddock, lower part	144	198	322

4.4.3 Soil samples

Three collection samples were taken from the bases of the upper (feeding and drinking area) and lower parts of the open stable paddocks in May 2002. The collection sample comprised ten separate random samples taken with a specific soil bore from depth of 0 – 12 cm. The soil samples were analysed by the Soil Analysis Service (Mikkeli, Finland) and the properties determined were conductivity, pH and the phosphorus, potassium and nitrate content.

4.5 Statistical analyses

The statistical analyses were carried out with the statistical software package SPSS 10.0 for Windows. Statistical differences between the measured qualities were detected with the non-parametric Kruskal-Wallis Test (I – IV) and Mann-Whitney U Test (II, III, IV), which are suitable for statistical analysis of data with a small number of analogous samples and an abnormal distribution. Results of exact signification from the Mann-Whitney U Test were multiplied by the Bonferron correction factor because of the small number of analogous samples in IV. According to the number of tests done, the Bonferron correction factor was three.

The correlation between the measured qualities of the peat materials was determined by calculating the non-parametric Spearman's correlation coefficient (r) (II). The statistical analysis of the triangle test results for the tastes of the vegetables (III) was done with a table of minimum numbers of correct judgements to establish significance at various probability levels for the triangle test (Roessler et al., 1978). The finding was considered statistically significant when the p-value was less than 0.05.

5 RESULTS

5.1 Quality of bedding materials (I, II)

5.1.1 Ammonia adsorption capacity (I)

The relative ammonia adsorption capacity of the bedding materials at +17.4°C, in descending order from most adsorbent to least adsorbent, was as follows: peat, linen, sawdust, hemp, shredded newspaper, wood shavings, straw (Fig. 2). Peat adsorbed ammonia at a level of 62.5 ppm/h. As the graph shows, there were clear differences in the ammonia adsorption capacity of the studied bedding materials ($p < 0.05$). For example, the ammonia adsorption capacity of peat was more than twice that of wood shavings. Hemp, sawdust and linen adsorbed from 60 – 75% of the ammonia released from fresh urine.

5.1.2 Water absorption capacity (I)

The water absorption capacity of the bedding materials, in descending order, was as follows: sawdust, peat, linen, hemp, shredded newspaper, wood shavings, straw (Fig. 3). The amount of bedding needed to hold 10 litres of water varied significantly between the studied materials ($p < 0.01$). The water absorption capacity of wood shavings and shredded newspaper was similar and about half that of peat.

5.1.3 Bacteria, fungi and endotoxin (I, II)

Shredded newspaper, sawdust and wood shavings contained lower amounts of micro-organisms than peat, linen, hemp and straw (I, Table 2). In addition, the microbial quality of different peat materials varied significantly ($p < 0.01$) (II, Tables 2 and 4).

Light, weakly decomposed sphagnum peat contained the least fungi, but significantly more endotoxin than other peat materials ($p < 0.01$). The content of mesophilic and thermotolerant fungi was highest in light, weakly decomposed sphagnum peat that warmed up to over 30°C during storage. Thermophilic actinomycetes were found only in the most decomposed few-flowered sedge peat (von Post H 4-5). (II)

Penicillium was the main fungus in all the peat materials studied. Yeast, the *Aspergillus fumigatus* fungus and *Trichoderma* fungus were present only in the more decomposed few-flowered sedge peat materials (von Post H 3-5). The concentration of endotoxin released into

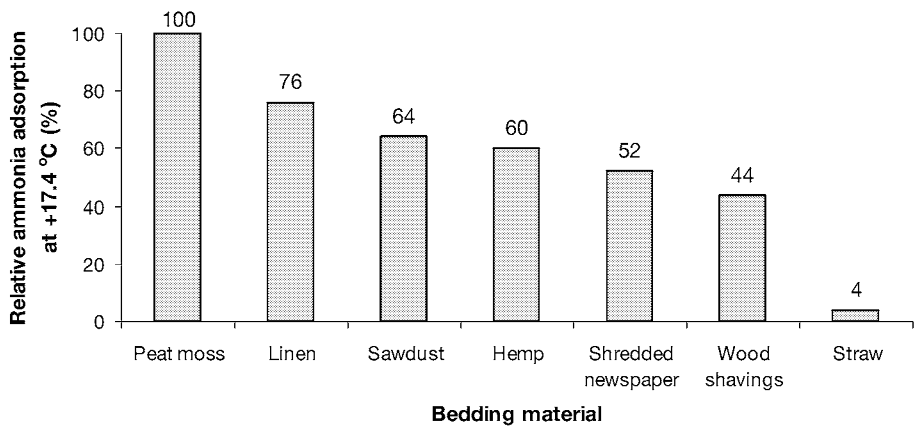

Fig. 2. Relative ammonia adsorption capacity of bedding materials at +17.4°C (modified from I, Table 1a).

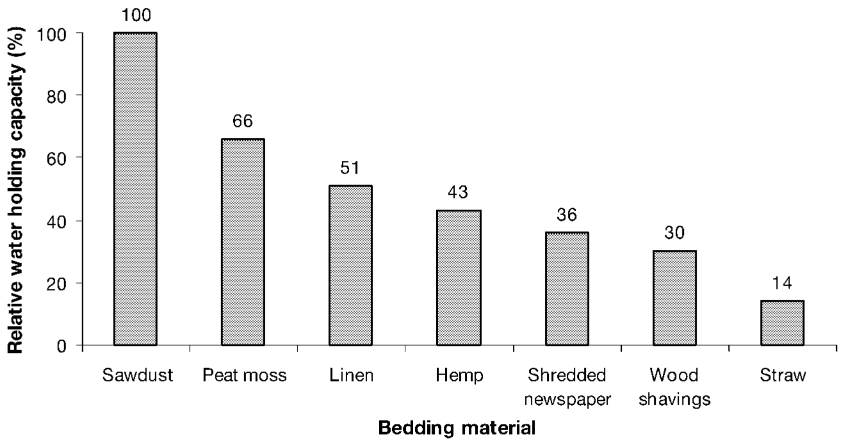

Fig. 3. Relative water holding capacity of bedding materials at room temperature (based on I, Table 1a).

the air during cylinder rotation of the peat materials varied from 280 EU/m³ (more decomposed few-flowered sedge peat, von Post H 3-4) to 73,000 EU/m³ (light, weakly decomposed sphagnum peat, von Post H 1-2). (II)

5.1.4 Dustiness of peat (II)

Light, weakly decomposed sphagnum peat contained significantly more inhalable dust than the other peat materials studied ($p < 0.01$) (II, Table 3). The concentrations of respirable dust in light, weakly decomposed sphagnum peat (von Post H 1-2, DM-content 73 – 75%) were about 10 times those in the more decomposed few-flowered sedge peat materials (von Post H 3-5, DM-content 56 – 59%).

The numbers of particles of all sizes (0.3 – 10 µm) were highest in light, weakly decomposed sphagnum peat ($p < 0.02$). The difference in the number of particles of 3 – 10 µm was over 350-fold between light sphagnum peat (von Post 1-2) and more decomposed few-flowered sedge peat (von Post H 4-5). There was variation in the amount of 3 – 5 µm-sized particles released from the peat material onto the cylinder during the rotation periods (II, Fig. 1). The number of particles was higher in the first rotation period than in the second period in light, weakly decomposed sphagnum peat warmed up in storage (von Post H 1-2) and more decomposed few-flowered sedge peat (von Post H 3-4). The rotation of the cylinder slightly increased the amount of particles of 3 – 5 µm in all the peat materials studied.

5.1.5 Bedding and quantity of produced horse manure (I)

The volume of manure produced with straw bedding was about twice that of manure produced with the other bedding materials (I, Table 3). The amount of removed bedding manure was similar to the amount of bedding material used in the stable.

5.1.6 Compostability of horse manure (I)

Composting of bedding manure started quite quickly in every composting box. The temperature of the composting mass was over +20ºC during the first 2 – 3 weeks and then fell to the level of the outdoor temperature (Fig 4). There were no remarkable differences between the temperature curves of the composting boxes at the depths of 10, 22 and 30 cm, indicating that the microbial activity was equally high in all these layers. No great increase in temperature

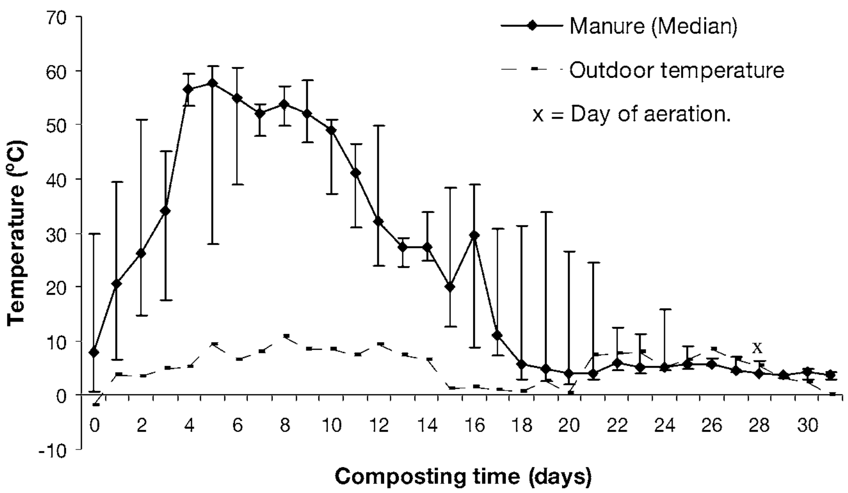

Fig. 4. Horse manure composting study in October – November. Median and range of the mass temperature in the compost boxes (V=1 m^3) with hemp, shredded newspaper, straw and peat moss/straw at a depth of 22 cm (n=4) (modified from I, Fig. 3). The compost and outdoor temperatures were measured once a day in the morning.

was found after turning the composting masses upside down four weeks after starting the study. After three weeks of storage in the composting box, the mass was dry especially with hemp, straw, wood shavings and shredded newspaper.

After a month of composting, a large amount of horse dung had crumbled and decomposed to smaller particles while the bedding material had remained almost unchanged. According to germination tests, the rubbish heap seeds in the manure were destroyed during composting.

5.1.7 Fertilization value of horse manure (I)

The relative content of soluble nitrogen in the different bedding manures after three weeks of composting, in descending order, was as follows: peat, peat/sawdust, peat/wood shavings, shredded newspaper, peat/straw, wood shavings, straw, hemp (Table 12). The concentration of soluble nitrogen in peat manure was about 1 kg/m^3. The content of phosphorus and potassium did not change during manure storage (I, Table 4).

Table 12. The relative value of soluble nitrogen in the bedding manure after three weeks of composting (based on kg soluble nitrogen/kg wet basis shown in I, Fig. 4).

Bedding and relative value of soluble nitrogen in manure			
Peat	100	Peat/straw (3:1)	48
Peat/sawdust (3:1)	85	Wood shavings	41
Peat/wood shavings (3:1)	77	Straw	33
Shredded newspaper	65	Hemp	23

5.2 Utilization of composted horse manure with peat bedding in greenhouse cultivation (III)

5.2.1 Yields

Composted horse manure with peat bedding was found to be a suitable fertilizer in the organic greenhouse cultivation of tomatoes, cucumbers and sweet peppers. The yields of tomatoes with different fertilization, in descending order, were as follows: 25 kg/m^2 (composted horse manure with peat bedding), 22.5 kg/m^2 (composted horse manure with peat bedding + Basic Fertilizer for Organic Cultivation (Kemira) + Chicken Manure (Biolan)), 21.0 kg/m^2 (composted cattle manure + Basic Fertilizer for Organic Cultivation (Kemira) + Chicken Manure (Biolan)).

The yield of cucumbers fertilized with horse manure (8 kg/m^2) was more than twice that with cattle manure fertilization (3 kg/m^2).

Similarly, the yield of sweet peppers fertilized with composted horse manure with peat bedding (10 kg/m^2) was twice that of sweet peppers fertilized with chicken manure (5 kg/m^3). The nutrient release from composted horse manure with peat bedding lasted longer than that from the control fertilizers, which was also found to reduce the need for further fertilization.

5.2.2 Nitrate and sugar content of vegetables

Nitrate concentrations were low in all the vegetables studied. There was no significant difference between the sugar concentrations of vegetables grown with different fertilizers. The taste of sweet peppers fertilized with composted horse manure was assessed as less sweet than those fertilized with the control fertilizer by young tasters (under 30 years old, $p < 0.01$). There were no significant differences between the tastes of tomatoes and cucumbers grown with different fertilizers. No taste defects were found in the studied vegetables grown with different fertilizers.

5.2.3 Hygienic quality of vegetables

The hygienic quality of vegetables fertilized with horse manure with peat bedding was found to be excellent. There were no faecal microbes in vegetables fertilized with composted horse manure.

In contrast, cucumbers fertilized with composted cattle manure were contaminated with faecal coliforms (980CFU/g). The number of coliphages in cucumbers fertilized with composted cattle manure was 260PFU/g, verifying the faecal contamination.

5.3 Surface water effects of manure management in paddocks (IV)

5.3.1 Dung loading in paddocks and nutrients in soil samples

It was estimated that about 3,500 kg of dung was removed from the cleaned paddock (area 800 m^2 with three horses) in the seven months from Oct 2001 to Apr 2002. The total dung loading in the paddock was higher because of problems with cleaning in winter. The collected amount of horse dung was estimated to contain about 8 kg of total phosphorus, 9 kg of potassium and 2 kg of soluble nitrogen. The potassium and phosphorus content and the conductivity and pH of the soil were higher in the feeding areas of the cleaned (A) and uncleaned (B) paddocks than in the other areas of these paddocks (IV, Table 1). This meant higher nutrient loading in the upper parts of the horse paddocks than in the lower parts. Even so, the differences between the studied areas were not statistically significant.

5.3.2 Nutrients in surface run-off

The horses defecated mainly in the feeding and drinking area. Surface water from the upper part (feeding area) of paddock B was found to contain more nutrients and enteric microbes than water from paddock A. Daily removal of dung was

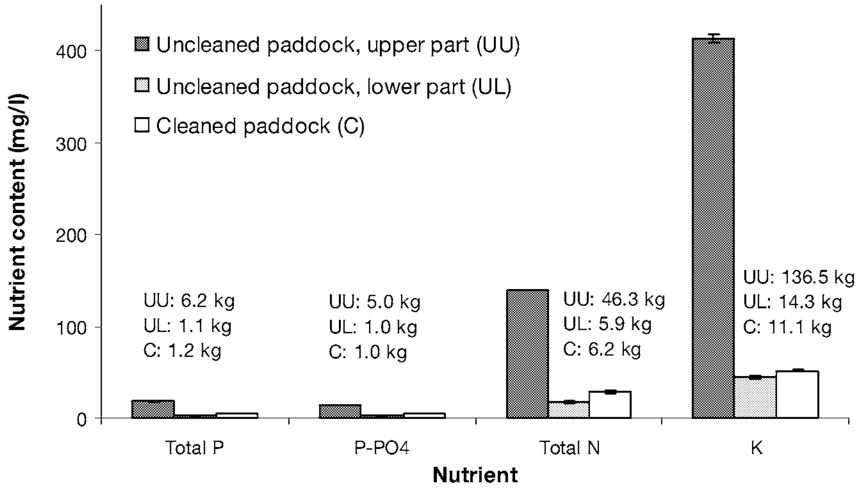

Fig. 5. Average and standard deviation of nutrient contents (mg/l) in the surface run-off waters from the cleaned and uncleaned paddocks in May, seven months (n=4) after the horses had been housed in the open stable (based on IV, Table 2) as well as the total amount of nutrients in the collection wells (kg) on 6 May 2002. Feeding areas were situated in the upper part of both paddocks.

found to greatly reduce the content of nutrients and the number of micro-organisms in the surface run-off, even though significant differences in water quality could not be shown.

The content of total phosphorus, phosphate and total nitrogen in the surface run-off from paddock B was many times higher in spring 2002 than in autumn 2001 (IV, Table 2). The content of nutrients in the surface run-off from both paddocks increased during the time that the horses spent in the open stable. In May 2002, the surface run-off from the feeding area of paddock B contained 80 – 90% more ammonium and almost 90% more potassium than the surface run-off from the lower part of that paddock or from paddock A (Fig. 5). The water samples showed that the quality of surface run-off was similar in the spring and summer, when the concentration of nitrate in the surface run-off was very low.

5.3.3 Microbial quantity of different groups in surface run-off

Apart from the content of coliforms, the surface run-off in the upper (feeding area) part of the uncleaned paddock was slightly dirtier than in the lower part of the paddock in spring 2002 (IV, Table 3). At the same time, the microbial quantity of different groups in the surface water was quite similar in the cleaned paddock and in the upper part of uncleaned paddock. In spring, the surface run-off from the cleaned paddock (A) contained higher numbers of culturable micro-organisms and faecal enterococci than the surface run-off from the lower part of the uncleaned paddock (B). Measurements in summer 2002 indicated a lower content of culturable micro-organisms and faecal enterococci in the surface run-off from paddock A than from paddock B.

6 DISCUSSION

6.1 Quality of bedding materials and their effect on stable air hygiene

6.1.1 Ammonia adsorption and liquid absorption capacity

The ammonia adsorption capacity of the bedding materials (I) was similar to earlier findings (Vahala, 1982; Kemppainen, 1985; Raymond et al., 1994b). The importance of the excellent ammonia adsorption capacity of peat is marked both in summer, when the indoor temperature in the animal house rises (Slobodzian-Ksenicz & Kuczyñski, 2000), and in winter when ventilation of the stable should be reduced because of the cold weather, especially since respiratory diseases of both stable workers and stabled horses have been strongly associated with airborne contaminants like ammonia gas and organic dust (Clarke, 1987; Holcombe et al., 2001; Omland, 2002; Frank et al., 2004).

The poor ammonia adsorption capacity of straw could be improved by chopping (Jeppsson, 1999; Slobodzian-Ksenicz & Kuczyñski, 2002), which may, however, increase the content of dust released from the material. Ammonia emission from manure with straw bedding may be reduced by using a large quantity of straw in box stalls with a high indoor air volume, as is done in Central Europe, by more intensive box stall cleaning and by the addition of peat into the bedding base (Jeppson, 1999). However, the effect of a straw/peat mixture on the microbial quality of the indoor air in stables and loose houses should be studied.

The results (I) for the water absorption capacity of straw, wood shavings (Peltola et al. 1996; Ward et al., 2000), shredded paper (Ward et al., 2000) and peat (Peltola et al., 1986) were similar to earlier findings. The absorption capacity of a material is connected to the frequency of bedding handling and, thus, to the content of dust released while bedding is handled. Sawdust held water better in this study than Peltola et al. (1986) have reported, and it is likely that the particle size of the sawdust used in study I was different from that used in their study. The effect of the particle size on the quality of sawdust should be studied further.

According to the volumetric need for bedding material, some degree of similarity may be seen in the quality of the studied materials as regards ammonia adsorption and liquid absorption capacity (Table 13). This is an important finding, since the bedding use of a poor absorbent means more bedding handling when compared to a better absorbent.

Table 13. Ammonia adsorption and liquid absorption capacity of bedding materials.

	Quality of bedding material			
	Very good	Good	Quite good	Poor
Ammonia adsorption capacity	Peat	Hemp Linen Shredded newspaper Sawdust	Wood shavings	Straw
Liquid absorption capacity	Peat Sawdust	Hemp Linen Shredded newspaper	Wood shavings	Straw

6.1.2 Occurrence of microbial groups and dustiness

Despite the small number of analogous samples, some trends could be seen in the occurrence of microbial groups in the studied bedding materials. Regarding the microbial quality of peat, these results agreed with the findings of Lappalainen (2002) and Mäittälä et al. (2001), and peat may be seen as a bedding material containing a lot of microbes and fungi (I, II).

The numbers of mesophilic fungi, xerophilic fungi and thermotolerant fungi were lower in straw than in peat, linen or wood shavings. The numbers of mesophilic fungi and thermophilic actinomycetes in straw were similar to the levels reported by Mäittälä et al. (2002). Wood shavings contained more mesophilic fungi (10^5 – 10^6 CFU/g) than was found in the study by Lappalainen (2002) (10^3 CFU/g). In agreement with Ward et al. (2001), the microbial content of shredded newspaper was low. (I)

As with Mäittälä et al. (2001), *Penicillium* was the main fungus in all the peat materials examined. Mesophilic yeasts, said to be one of the main species in clean peat (Mäittälä et al., 2001), were not found in weakly decomposed sphagnum peat (von Post H 1-2). The bedding quality of the more decomposed few-flowered sedge peat materials (von Post H 3-5) was reduced due to the appearance of *Aspergillus fumigatus* fungi and thermophilic actinomycetes (Kotimaa, 1990b; Eder et al., 2000). The occurrence of *Trichoderma* in the few-flowered sedge peat materials was seen as a sign of the far-advanced decomposition of those materials. (II)

There was a significant variation in the dustiness and endotoxin content of the peat materials (II). This finding is important, since inhaled endotoxin and organic dust particulates can induce pulmonary inflammatory responses and result in respiratory diseases both in humans (Omland, 2002) and horses (McGorum, 1998; Pirie et al., 2003). Weakly decomposed sphagnum peat (von Post H 1-2), characterized as a good bedding material (Peltola et al., 1986), was found to release a significantly higher content of inhalable dust, respirable dust and endotoxin into the air during cylinder rotation than the other peat materials.

In agreement with Kotimaa et al. (1991), the dustiness of bedding may be partly explained by the low water content of the material. One reason for the high endotoxin content may be the low stage of decomposition in sphagnum peat. Correspondingly, the early stage of cotton textile processing has also generated high endotoxin and bacteria contamination (Su et al., 2002). It is possible that bacteria and endotoxin in the slightly decomposed peat were destroyed by fungi during the further decomposition of the peat. Warming up of the peat in II, caused by microbial activity, increased the number of fungi in the material, as was also found by Ranneklev and Gislerød (2001), but, on the other hand, it reduced the content of endotoxin in light, weakly decomposed sphagnum peat. The effect of warming up on the endotoxin content of peat needs to be studied further.

The grinding of peat inferred in II might also happen in bedding use, especially when dry peat material is used. The number of particles of ≤ 5 μm in the air released during handling of the more decomposed few-flowered sedge peat was the same as that reported for good quality straw and wood shavings (Vandenput et al., 1997).

Laboratory conditions improved the comparison of different peat materials in II. However, the results of this study could not be compared directly with the occupational exposure limits for organic inhalable dust (Finnish Ministry of Social Affairs and Health, 2000), nor the air quality measured from agricultural environments (Kotimaa, 1990; Tanner et al., 1998; Mäittälä et al., 2001; Lappalainen, 2002; Rieger et al., 2002; Rautiala et al., 2003). In addition, the rotation of the peat material in a cylinder may be considered more aggressive handling than that received by bedding used in horse stables.

The moisture content of the studied peat materials (25 – 44%) was distinctly under 50%, which value is suggested to minimize the dust content of the air during peat bedding handling

(Larsson et al., 1999). Although the dust problem with some bedding materials might be lessened by the addition of water, special attention should be paid to the development of dustless bedding. Bedding use of dusty peat cannot be recommended even though peat is an excellent ammonia adsorbent and liquid absorbent. However, dustless peat bedding might also have potential as a product for export, but only if there is a positive attitude towards the use of peat.

The dustiness and microbial quality of bedding have mostly been studied in working environments. However, comparison of bedding materials is difficult both because of their internal heterogeneity and the external influences affecting the study results. It should be understood that the content of dry matter (Larsson et al., 1999) as well as harvesting and storage conditions might have a significant effect on the quality of bedding material (Kotimaa et al., 1991; Airaksinen, 2004). Thus, it is likely that there is more variety in the microbial quality of peat, straw, hemp and linen than with wood bedding materials (Table 14).

6.2 Effect of bedding and manure management on the environmental impact of horse stables

6.2.1 Compostability of horse manure

The quality of bedding material as well as the working practices of stable workers may have a great effect on the amount of manure removed from box stalls into storage (Swinker et al., 1997). Removal of dirty bedding was easiest and quickest with peat and hemp bedding (I). Removal of dirty wood shavings, shredded newspaper, and straw took more time because of the difficulty in separating clean and dirty bedding material.

Contrary to earlier findings (Moncol, 1996), there were no great differences in temperature development between the bedding materials during the composting study. However, the starting temperature (day 0) in the manure compost with hemp bedding was higher than in the manure composts with shredded newspaper, straw and peat/straw mixture (I, Fig. 2). That may be because the hemp manure started decomposing when the compost boxes were being filled.

Composting of manure is needed for the destruction of potential animal and plant pathogens (Steineck et al., 2000) and the decomposition of bedding (Tiquia & Tam, 2000). The temperature in all the composting boxes reached rapidly 40.7°C, which temperature has been reported to kill most of the strongyle ovae and larvae from horse manure (Moncol, 1996). No great increase in temperature was noticed after turning the composting masses upside down. Lack of oxygen could not, therefore, have been the only reason for the decreasing biological activity of the composting mass after three weeks of storage. The limiting factors were supposed to have been the moisture, soluble carbon and soluble nitrogen content of the

Table 14. Microbial quality and dustiness of bedding materials with regard to stable air quality.

Material	Microbial quality and dustiness of bedding material
Peat	Variable, connected to decomposition grade and conditions of material harvesting and storage.
Straw	Variable, connected to conditions of material harvesting and storage.
Hemp	Variable, connected to conditions of material harvesting and storage.
Linen	Variable, connected to conditions of material harvesting and storage.
Wood shavings	Variable, connected to the material's particle size and conditions of storage.
Sawdust	Variable, connected to the material's particle size and conditions of storage.
Shredded newspaper	No problems.

manure compost, so that the composting had already ended. (I)

Horse faeces were quite well decomposed after a month of composting in a covered composting box (I). However, only manure with peat bedding would have been ready for utilization after a month of composting. The other bedding materials were decomposed only to a small extent or not at all in the composting boxes. Decomposition of bedding is necessary since the use of manure with a lot of raw bedding for fertilization may cause a reduction in yield (Kemppainen, 1983; Tiquia & Tam, 2000). Decomposition of bedding material in horse manure storage and its effect on plant utilization of manure is estimated in Table 15. Ammonia emission during composting of horse manure was clearly lower from the manure with peat bedding than from the manure with wood shavings (I). That is an important finding when the environmental effects of manure storage and the fertilization value of manure are assessed. Any soluble nitrogen losses from manure compost lower the fertilization value of the manure (Tiquia & Tam, 2000). The fertilization value of composted horse manure with peat bedding was found to be better than the other bedding manures in I.

Differences in the retention of soluble nitrogen may be explained by the ammonia adsorption and liquid absorption capacity of the bedding materials. It should be noted that the concentration of soluble nitrogen in straw (% of fresh weight basis) is reported to be over three-fold when compared to peat material and wood chips (Kapuinen, 1996). In agreement with Preusch et al. (2002), the content of phosphorus and potassium were quite unchanged during storage of manure in I. Differences in the content of those main nutrients may be explained by the heterogeneousness of the manures and lack of analogous samples affecting the result. The effect of bedding materials on nutrient leaching from manure compost was not studied.

6.2.2 Plant utilization of composted horse manure

Manure is reported to be a suitable fertilizer for late-ripening plants like potatoes (Karinen et al., 2005), vegetables and grass and effect like a soil improvement material especially when spread on the clay-containing soil (Kemppainen, 1983). According to the results of III, composted horse manure with peat bedding may also be used successfully in the organic greenhouse cultivation of tomatoes, cucumbers and sweet peppers. It may be due to the soil structure improving properties of peat that the nutrient release from composted horse manure lasted longer than that from the control fertilizers, giving higher yields and reducing the need for further fertilization (III). The possibility of manure plant utilization, as was found with peat manure in III, promotes the idea of an ecologically sustainable manure management chain.

Table 15. Estimation of the decomposition of bedding material in horse manure storage and its effect on plant utilization of manure

Material	Decomposition of bedding in manure storage	Plant utilization of manure
Peat	Quick	Easy
Straw	Quite quick	Quite easy
Hemp	Quite quick	Quite easy
Linen	Quite quick	Quite easy
Wood shavings	Slow	Problematic
Sawdust	Slow	Problematic
Shredded newspaper	Slow	Problematic

The yields of tomatoes, cucumbers and sweet peppers fertilized with composted horse manure with peat in III were good for yields from organic cultivation (Information Centre of the Ministry of Agriculture and Forestry, 2001). In addition, the hygienic quality of vegetables fertilized with composted horse manure was found to be excellent, as presented in paper III. That may be due to the far-advanced decomposition of stored peat manure (I). Well-managed composting of manure is important because it is possible for the edible part of a plant to become contaminated with a pathogen also by the roots (Solomon et al., 2002). Faecal bacteria were found in cucumbers fertilized with composted cattle manure, which may be explained by its poor composting. This finding is very important since the use of cattle manure as a fertilizer is common in organic cultivation.

In III, the taste of sweet peppers fertilized with composted horse manure was less sweet than those fertilized with pure chicken manure, maybe due to more rapid growth leading to earlier ripeness and richness of organic acids or aroma compounds covering the sweet taste. There was no significant difference between the sugar concentrations of vegetables grown with different fertilizers. The lack of sweetness in a vegetable should not necessarily be seen as a fault, because there are differences in the tastes of customers. The utilization of composted horse manure with peat bedding, e.g. in year-round greenhouse cultivation of organic tomatoes, should be studied.

It is reasonable both economically and for environmental protection that winter-stored horse manure may be utilized in plant cultivation during the next growing season. However, further research and practical instruction as well as close cooperation between urban stables and farmers is needed to increase the plant utilization of horse manure even with bedding materials like peat or straw. In Sweden, there are already some entrepreneurs who collect horse manure from urban stables, compost manure in large stores and utilize it in plant cultivation (Andersson, 2005).

Since manure dumping in landfills (Council of State Decision No. 861/1997) and manure combustion (Government Decree No. 362/2003) became restricted, some ecologically and economically reasonable ways of utilizing wood-based horse manure should be found. Manure exploitation is a real problem especially for big stables located in urban areas using wood bedding and having no land for manure spreading. Watering, turning and the addition of nitrogen are methods which may improve the decomposition of wood-based manure but, on the other hand, they will cause extra work and expense, and, moreover, it has been found that increasing the turning frequency of composted manure may also increase nutrient losses from manure compost (Parkinson et al., 2004). Both the utilization of wood-based manure in the composting process of sewage sludge and the effects of horse manure combustion in farm-scale plants should be studied. Comprehensive comparison of the cost of bedding and manure management in horse stables was not done in this study.

6.2.3 Manure management in horse paddocks

Daily dung removal reduced the content of nutrients and microbes in surface run-off water significantly, even though there were problems with dung removal in winter (IV). In agreement with the study results from cattle pens (Uusi-Kämppä et al., 2003; Saarijärvi et al., 2004), dung-load was higher in the feeding area than in the other parts of the paddock. Thus, special attention should be paid at least to the cleaning of drinking and feeding places in horse paddocks and especially in paddocks combined with an open stable. Also the location of surface water collection wells near those most contaminated areas might be reasonable.

The concentration of total phosphorus in the surface water from the feeding area of the uncleaned paddock in spring after seven months of use was 40-fold and soluble phosphate 125-fold when compared to water from field ditches (0.47 mg/l; 0.12 mg/l) as reported by Rekolainen

(1993). The content of phosphate in the surface water from the feeding area of the uncleaned paddock was similar to that measured from a winter pen for eight suckler cows (Uusi-Kämppä, 2002). The concentration of total nitrogen in the surface water from the feeding area of the uncleaned paddock was similar to that found in manure composting leachate (Karlsson & Torstensson, 2003) and, thus, high compared to those in water from Finnish lakes and rivers (Räike et al., 2003) and even to limits for wastewater effluents (often <10 mg/l) (Council of State Decision No. 757/1998). Most of the total nitrogen found was in the form of ammonium, as was also the case with a cattle pasture and winter pen (Hallberg, 1989; Uusi-Kämppä et al., 2003). The high nitrogen without nitrate may be a sign of low redox potential, since oxygen is taken for the degradation of organic compounds like dung.

The differences in nutrient and microbe content between different parts of the uncleaned paddock may be because the horses defecated mainly in the feeding and drinking areas of the paddocks, and onto paths by hedges, which was proved by the soil analyses in IV. Surface run-off from the cleaned paddock was sometimes dirtier than that from the lower part of the uncleaned paddock, which may be largely explained by the difficulty in removing dung, especially after snowfall.

The surface areas of the paddocks used in IV conformed with the recommendation of the Equestrian Federation of Finland (Suomen Ratsastajainliitto ry, 2005). It should be noted that the minimum surface area of a paddock for three horses is only 6% of the same value for pasture (Finnish Ministry of Agriculture and Forestry, 2000; Suomen Ratsastajainliitto ry, 2005). Since the size of stables is increasing (Heiskanen et al., 2002) and horses spend more and more time outside in paddocks that may be situated near lake and river systems, there is a high risk of nutrient and microbe leaching into waters, particularly in the case of paddocks with high horse density, high sloping ground and no vegetation.

It is concluded that the recommendation of regular dung removal from horse paddocks (Finnish Ministry of the Environment, 2003) is justified for reasons of environmental protection. Altogether, it is very reasonable that the nutrients in collected excreta can be used in plant cultivation after excreta composting in storage. Special attention should be paid to finding more efficient methods of dung removal in winter. In addition, the effects of operating time, base material and horse density on the environmental impact of horse paddocks should be studied further.

7 CONCLUSIONS

It is very important that the bedding material reduces the content of indoor air impurities in a stable. It is likely that there is more variety in the microbial quality of peat, straw, hemp and linen than with wood bedding materials. Bedding material may contain a lot of organic dust and harmful microbes, as was found with the studied peat materials. Dusty material cannot be recommended for horse bedding even though it was a good ammonia adsorbent and liquid absorbent and decomposed quickly in manure storage. Thus, special attention should be paid to the development of dustless bedding.

Contrary to the general presumption, bedding material did not prevent the decomposition of horse manure when the amount of bedding was small enough and the environmental factors for composting were good. However, the decomposition of the studied wood shavings, sawdust and shredded newspaper was extremely slow in manure compost compared to the plant materials in this study. Due to the excellent ammonia adsorption capacity of peat materials, it is likely that ammonia emissions from manure storage with peat are lower and the fertilization value of peat manure is higher than with the bedding use of wood shavings.

According to EU regulations, horse manure should be exploited primarily as a fertilizer in plant cultivation. Plant utilization of winter-stored horse manure should not be a problem if materials like peat or straw are used as bedding. In this study, composted horse manure with peat bedding was found to be a suitable fertilizer in the organic greenhouse cultivation of tomatoes, cucumbers and sweet peppers. However, further research and practical instruction as well as closer cooperation between urban stables and farmers is required in order to increase the fertilization use of horse manure. In addition, some ecologically and economically reasonable ways of utilizing horse manure with wood bedding should be found.

The number of horses is increasing and horse stables are more often situated in urban areas or near cities as well as near lake and river systems. In order to minimize the nutrient and microbe content in surface waters from horse paddocks and thus the negative environmental effects of horse stables, the excreta from paddocks should be removed regularly. Special attention should be paid to the cleaning of feeding and drinking places, which are probably the most contaminated areas in a paddock. It is of great value that the nutrients in collected dung can be used in plant cultivation after dung composting in storage. The effects of operating time, base material and horse density on the environmental impact of horse paddocks should be studied further. Also, more efficient methods of dung removal in winter are needed.

The effect of bedding and manure management on the health of young stable workers, horse hobbyists and athletic horses as well as the environmental impact of horse establishments should be considered in order to achieve a hygienic and environmentally acceptable chain of horse manure management.

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