Measures to mitigate nitrogen and phosphorous losses can reduce the risk of disease transmission from manure

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Abstract
Biosecurity [1] consideration may provide an extra incentive for improved manure management practices. Therefore we evaluated the potential reduction of pathogen transmission for 25 agricultural measures that can be used to reduce nitrogen and phosphorus leakage from agricultural practices. Nitrogen (N) is more easily transported through soil than are pathogens, and hence a larger part will leak through drainage water and to groundwater. Phosphorus (P), on the other hand, binds harder to soil particles, and in that sense is more likely to be reduced in the same pattern as many pathogens. The difference is that, while pathogens are inactivated over time, P in the soil is in a stable ion form, so that erosion is relatively more important for P than for pathogen leakage. The common denominator for nutrients and pathogens is surface runoff, and reducing the risk of surface runoff will therefore have multiple benefits. Manure management is pertinent in reducing biosecurity risks. This means proper storage (no risk of leakage to water, time for pathogen inactivation), treatment to inactivate pathogens (optional), time and technique of application, implement a buffer strip when fields are adjacent to water, whereas fields close to water with a significant slope (>10%) should not be fertilised at all. Reducing run-off will not only provide risk mitigation in terms of pathogens but will also reduce faecal indicator transmission to surface water and therefore important at sites close to beaches in order to fulfil the Bathing Water Directive (2006/7/EC).

Introduction
Land application of manure serves several purposes. Not only is it a practical solution to waste handling but it also contributes to recycling of valuable plant nutrients, such as nitrogen, phosphorus, sulphur and potassium, as well as some essential micro nutrients, such as nickel, zinc and copper. Addition of manure can further improve soil properties such as structure and water-holding capacity [1]. However, recycling of manure may also serve as a transmission route for pathogens to the environment causing problems with zoonotic pathogens in the food chain and the risk of transmission of highly contagious animal diseases between herds [2]. Due to an intensified animal production in the Baltic Sea Region, and a changing climate, there is a potential increasing risk of transmission of infectious disease agents from animal farms to the water environment. When pathogens end up in surface water, humans can be exposed through recreational activities such as swimming, consumption of leafy greens irrigated with contaminated water, and drinking tap water produced from contaminated water [3].

Zoonoses can be transmitted from animals to humans, for example via the food chain and in contact with contaminated water. They include *Salmonella* spp., *Campylobacter jejuni*, verotoxin-producing *Escherichia coli* (VTEC, EHEC), *Cryptosporidium parvum* and hepatitis E virus. Animal pathogens (pests) spread faecally-orally can potentially be transmitted via water. However, this has not been investigated to the same extent as for waterborne human diseases. Animal-to-animal transmission is probably more significant, but water has been shown to act as a vector for *Salmonella* spp. and VTEC transmission between herds in Sweden [4]. Many

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[1] The term *biosecurity* is used widely and usage varies between sectors and countries. The Food and Agricultural Organization of the United Nations (FAO) has a wide definition of biosecurity as:
"A strategic and integrated approach that encompasses the policy and regulatory frameworks (including instruments and activities) that analyse and manage risks in the sectors of food safety, animal life and health, and plant life and health, including associated environmental risk. Biosecurity covers the introduction of plant pests, animal pests and diseases, and zoonoses, the introduction and release of genetically modified organisms (GMOs) and their products, and the introduction and management of invasive alien species and genotypes. Biosecurity is a holistic concept of direct relevance to the sustainability of agriculture, food safety, and the protection of the environment, including biodiversity." (www.fao.org). However, reference to biosecurity considerations in this report is made with the focus on leakage of manure from the farm, *e.g.* transmission of infectious disease agents to the environment via manure run-off, and pathogens transmitted faecally-orally.

antibiotics used in veterinary medicine are only partially metabolised by treated animals and enter the environment with manure application as well as resistant bacteria shed by the treated animals [5]. Faecal indicators (*e.g. E. coli* and faecal enterococci) are part of the normal microbiota in mammals and are used in water management as markers of faecal pollution and hence health risks. The indicators are, in general, not pathogenic but can carry genes and plasmids coding for antibiotic resistance, which can be transmitted to closely related pathogens [6]. Another rationale for discussing faecal indicators and their transmission via manure is that *E. coli* and enterococci are mentioned in various guidelines such as the Bathing Water and Drinking Water Directives (2006/7/EC and 98/83/EC respectively) and manure run-off may prevent Member States from achieving compliance with these.

Partners in the Baltic Compass project identified 25 important agricultural measures that can be used to reduce nitrogen and phosphorus leakage from agricultural practices [7]. An important part of the nitrogen and phosphorous flows on and from the farm is manure. So, in addition, the effect on biosecurity (pathogen transmission from the farm) was considered for these 25 measures (Table 1). For further description of each measure we refer to the Summary of Country Report which can be found at www.balticcompass.org.

Materials and Methods

The assessment was performed through expert judgments and a literature review. In an initial meeting, the measures were defined on how and in what way they could affect biosecurity. Then each measure was judged by reading relevant literature. At a second meeting the effect of each measure was graded after a joint discussion on how effectively it could reduce pathogen leakage from manure: 0 = no effect; (+) can have a minor and/or an indirect effect (< 30% risk reduction); + has an effect (30%< x < 90%); ++ will reduce the risk significantly (>90%).

Results and discussion

Humans can be exposed to manure-contaminated water during recreational activities such as bathing. Epidemiological studies have shown that the rates of some adverse health outcomes, such as gastrointestinal disease, are higher in swimmers compared with non-swimmers and are correlated to the faecal contamination of the water [8]. Faecally contaminated surface water used for irrigation ends up on the surface of edible crops. Presently, there are no European guidelines either on irrigation water quality or on holding time between irrigation and harvest. Several *E. coli* O157 outbreaks from leafy greens have been reported [9]. Surface water is also extensively used as source water for drinking water production. In the water treatment plant, controlled removal and estimated inactivation takes place during disinfection processes. However, a specific challenge is the chlorine-resistant protozoan parasites *Cryptosporidium* and *Giardia* [10]. Groundwater treatment plants rely on the removal of pathogens through soil passage in order to provide water with high quality, and disinfection is rarely employed in Sweden. However, increased surface water impact of groundwater can take place during high flow events, and pathogens like *Campylobacte*r and EHEC can potentially cause problems in cattle-dense areas, and Hepatitis E virus in pig-dense areas [10]. Hence, upstream control of faecal pollution is highly important.

The most significant measures, scoring ++, were storage, avoiding high risk areas and periods, and buffer strips along water bodies. Apart from incorporation of manure all these measures had multiple benefits, reducing N and P losses as well (Table 1). Suitable storage reduces the risk of manure leakage. In addition, inactivation (time- and temperature-dependent) of pathogens takes place during storage. According to Guan and Holley [11] a storage time of 90 days at 25 °C is enough for acceptable inactivation of the zoonotic agents listed in the introduction (apart from HEV), while the potential exists to eliminate most pathogens at higher temperatures (> 50 °C) [2].

Table 1. *Characterisation of the 25 measures according to type (management and technology), effect (nitrogen, phosphorous and biosecurity) and popularity in the nine Baltic Sea region countries surveyed* [7]

Priority measures	Type [a]	Effect [b]	"Popularity" [c]	Biosecurity [d]
1. Promoting long-term grass cultivation on arable land	M	N/P	6	L, +
2. Vegetative cover in autumn and winter on arable land	M	N/P	9	L, (+)
3. Soil tillage management				
3.1. Reducing soil tillage	M/T	N/(P)	5	0
3.2 Time of the year effects	M	N/(P)	5	L, (+)
4. Fertilisation management				
4.1. Adapting the amounts of chemical fertiliser and manure applied	M/T	N/P	8	L, (+)
4.2. Calculating nutrient balances on farm and/or field level	M	N/(P)	6	0
4.3. Avoiding the spreading of chemical fertilisers and manure during high-risk periods	M	N/P	9	L, ++
4.4. No or reduced phosphorus fertiliser for high soil phosphorus fields or part of fields	M/T	P	7	0
5. Improved spreading technology for manure and chemical fertiliser				
5.1 Site-specific dosage	T	N	4	L, (+)
5.2 Combi-drilling	T	N	3	L, +
5.3 Incorporation	T	N	7	L, ++
5.4 Liquid manure	T	N	8	L, +
5.5 Solid manure	T	N	6	L, +
5.6 Manure spreading and ammonia emissions – general measures	M/T	N	6	L, (+)
6. Avoiding the application of chemical fertilisers and manure to high-risk areas	M	N/P	9	L, ++
7. Measures to optimise soil pH and improve soil structure	M	(P)	6	0
8. Adapted feeding				
8.1 Adopting phase feeding of livestock	M/T	N/P	0	AH, (+)
8.2 Reducing dietary nitrogen and phosphorus intake	M	N/P	1	0
8.3 Phytase supplementation	M	P	2	0
8.4 Wet feed and fermentation	M/T	P	0	0
9. Reducing ammonia losses in animal houses	M/T	N	3	AH, (+)
10. Storage of manure	M/T	N/P	9	L, ++
11. Constructed wetlands for nutrient reduction/retention				
11.1 Sedimentation ponds	M/T	P	3	L, +
11.2 Constructed wetlands	M/T	N/P	3	L, +
12. Buffer zones along water areas and erosion-sensitive field areas	M	N/P	9	L, ++

a) M = Management
T = Technology
M/T = Both Management and Technology

b) N = Nitrogen
P = Phosphorus
N/P = Both Nitrogen and Phosphorus
() = Uncertain effect

c) The number of countries with either legislation or subsidy, or both (max is 9)

d) AH = Improved animal health
L = Reduced surface run-off
0 = No effect
(+) = Can have a direct or indirect effect
+ = has an effect
++ = Will reduce the risk of pathogen leakage significantly

Vegetated buffer zones along watercourses are used to reduce the surface runoff of nutrients and pathogens from fields. Reduction of microorganisms across vegetated buffer zones depends on width, vegetation and slope [12]. Incorporation of manure will increase the pathogen survival time in soil compared to unincorporated manure on the soil surface [13]. However, leaving manure on the soil surface will increase the risk of disease transmission via surface runoff to waters. Furthermore, the possibility of pathogen spread to the wild fauna and transmission via vector animals will increase if manure is left on the surface. Ponds and constructed wetlands are used to polish secondary treated wastewater to reduce nitrogen, phosphorus and pathogen levels in receiving waters. However, the biosecurity effects will depend on the possible exposure of humans and livestock to the ponds/wetlands. Furthermore, ponds/wetlands serve as attractive bird habitats with the potential for vector transmission of pathogens, and as breeding grounds for mosquitoes. Measures which are beneficial for animal health can have an indirect effect through reducing the prevalence of pathogenic microorganisms. Further, healthy animals produce more and will less often be treated with antibiotics, hence leading to a reduction of antibiotic resistant bacteria transmitted (Table 1).

Conclusion and perspectives

Human and animal health perspectives are hardly considered in environmental directives. However, implementing measures to comply with environmental jurisdiction, *e.g.* the Nitrite Directive (91/676/EC), can also be beneficial from veterinary and public health perspectives. Manure management is pertinent in reducing biosecurity risks. This means proper storage (no risk of leakage to water, time for pathogen inactivation), treatment to inactivate pathogens (optional), time and technique of application, implement a buffer strip when fields are adjacent to water, whereas fields close to water with a significant slope (>10%) should not be fertilised at all. Further, we suggest that the Bathing Water Directive (2006/7/EC) should be implemented in the Water Framework Directive (2000/60/EC) as a means for microbial recipient based control.

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