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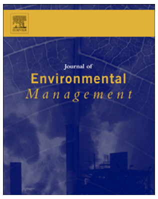

Review

Silage effluent management: A review

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ABSTRACT

Silage effluent is a potent wastewater that can be produced when ensiling crops that have a high moisture content (MC). Silage effluent can cause fish–kills and eutrophication due to its high biochemical oxygen demand (BOD) and nutrient content, respectively. It has a high acidity ($\text{pH} \approx 3.5–5$) making it corrosive to steel and damaging to concrete, which makes handling, storage and disposal a challenge. Although being recognized as a concentrated wastewater, most research has focused on preventing its production. Despite noted imprecision in effluent production models—and therefore limited ability to predict when effluent will flow—there has been little research aimed at identifying effective reactive management options, such as containment and natural treatment systems. Increasing climate variability and intensifying livestock agriculture are issues that will place a greater importance on developing comprehensive, multi–layered management strategies that include both preventative and reactive measures. This paper reviews important factors governing the production of effluent, approaches to minimize effluent flows as well as treatment and disposal options. The challenges of managing silage effluent are reviewed in the context of its chemical constituents. A multi-faceted approach should be utilized to minimize environmental risks associated with silage effluent. This includes: (i) managing crop moisture content prior to ensiling to reduce effluent production, (ii) ensuring the integrity of silos and effluent storages, and (iii) establishing infrastructure for effluent treatment and disposal. A more thorough investigation of constructed wetlands and vegetated infiltration areas for treating dilute silage effluent is needed. In particular, there should be efforts to improve natural treatment system design criteria by identifying pre–treatment processes and appropriate effluent loading rates. There is also a need for research aimed at understanding the effects of repeated land application of effluent on soil quality and crop yields, as spreading is a common disposal practice.

1. Introduction

Silage is fodder prepared by storing and fermenting a crop (e.g., forages, corn), and is important for livestock farms because it preserves quality feed for winter consumption. It is particularly important in cool, moist climates where the drying of hay is a challenge (McGechan, 1990). For perspective, from 1997 to 2007, US corn silage production increased from 89.2 to 104.2 Mt y^{-1} (USDA-NASS, 2013), and in 2010, 29% of the 3.8 million ha of Irish farm grasslands were used to grow silage crops (CSO, 2012). Silage making involves the anaerobic fermentation of soluble carbohydrates, which produces organic acids that inhibit the growth of microorganisms that would otherwise cause spoilage (Mason, 1988; McDonald et al., 1991). During this process, effluent (or leachate) may be produced—typically when the ensiled crop has a high moisture content (MC). Farmers face the challenge of ensiling the crop at an optimal MC that is wet enough to permit fermentation, yet dry enough to prevent the production of large effluent volumes. Effluent release during silage making represents a loss of silage dry matter (DM), and a reduction in the value of the silage as feed. These concerns motivated research aimed at reducing effluent production and release (Jones and Jones, 1995, 1996) to conserve crop quality. The reactive management of silage effluent using wastewater treatment processes has, however, received less attention, and is an issue that requires consideration due the high oxygen demand and nutrient content of this agricultural wastewater.

Silage effluent is high in biochemical oxygen demand (BOD), nitrogen (N), phosphorus (P), and has a low pH (Deans and Svoboda, 1992; Galanos et al., 1995). If discharged untreated, it can negatively impact surface and groundwater quality (Merriman, 1988;

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OMAFRA, 2004; Stekar, 1998). A particularly problematic characteristic is that it is extremely corrosive to steel and damaging to concrete due to high concentrations of organic acids (OMAFRA, 2004, 2008), making collection, storage and disposal challenging. Despite the high strength of silage effluent, there are few acts or regulations that specifically target its containment and disposal in North America—unlike the United Kingdom which has instituted regulations (e.g., NIDE, 2003; Scottish Ministers, 2001; SSEE/SSW, 1997) because of the significant challenges posed by their wet climate. Water protection in Canada and the United States is typically regulated indirectly by considering the effects of releasing deleterious wastes into the environment (e.g., Crozier (2004). Another aspect of indirect silage effluent regulation is through nutrient management acts, as the case in Ontario, Canada (Government of Ontario, 2002)). There are some jurisdictions that have legislated the direct management of silage effluent. In Wisconsin US, dairy producers with herds larger than 1000 head of milking cows have to implement a Pollutant Discharge Elimination System that plans how effluent and runoff are managed (Holmes, 2007); and in Minnesota, producers storing more than 1000 t of sweet corn silage must obtain a permit and manage leachate as a process wastewater (MPCA, 2012). Although there are some jurisdictions with legislation that specifically regulates silage effluent, in many areas this is not the case. It could be considered even more important to establish effective management practices in areas without direct silage effluent legislation to prevent pollution incidents and save farmers from having to deal with costly legal actions after incidents occur.

Many regions in North America are characterized by a humid climate with precipitation exceeding evapotranspiration during parts of the growing season. The potential for effluent production is therefore an issue because crops may have to be ensiled at higher than recommended MC. The warmer and wetter climate that is projected for most of North America, excluding the Southwest United States (Christensen et al., 2007), may make silage production more challenging because of the difficulty in obtaining an optimal crop MC through wilting or drying in the field. It is thus important to understand the issues related to silage effluent production, composition, treatment and disposal to support the development of effective management strategies. Previous research has largely focused on identifying the factors that regulate effluent production (Jones and Jones, 1995), and preventing effluent flow with absorbents (Jones and Jones, 1996; Razak et al., 2012) with little attention to treatment and disposal. Given the high variability in measured effluent flows, and the imprecision of predictive effluent flow models (Jones and Jones, 1995, 1996), it is insufficient to neglect treatment and disposal in favor of using only preventative methods based on controlling crop MC.

Therefore, the objective of this review was to synthesize the existing body of knowledge in the context of establishing a multi–faceted approach to silage effluent management. This involved reviewing (i) important factors that regulate effluent production, (ii) preventative measures to decrease effluent flows, (iii) containment, and (iv) treatment and disposal options. Key knowledge gaps that should be addressed by future research to support improved farm-level management were identified. We have attempted to present information in as broad a context as is practically possible, so that it may be of use to a diverse audience in the hope that local users will adapt the general concepts to their location. We therefore do not present a detailed discussion of region-specific practices, legislation or costs, but rather a generalized presentation of key points.

2. Silage effluent production

The objective of silage production is to ferment a crop to lower the pH to inhibit putrefying bacteria, thus preserving the protein content of the fodder (McDonald et al., 1991). Nutritionists recognized that ensiling at optimum MC is important to maximize digestibility and avoid losses from poor fermentation. In addition to the negative effects that ensiling high moisture crops has on silage quality such as clostridia fermentation (OMAFRA, 2012), there are increased risks of effluent production (Jones and Jones, 1995). Common silage crops include, but are not limited to, grasses, alfalfa, corn, and sugar beets. Grasses and alfalfa are cut and ensiled several times during the growing season, and may be wilted, in contrast to sugar beets and corn, which are harvested once per year. Upon cutting grasses and alfalfa, it is possible to reduce crop MC in the field through wilting, whereas corn dries down as a standing crop. This review will mainly consider grasses and corn, because these crops have been studied in the greatest detail.

Several factors affect effluent production rates including crop MC at ensiling, the vertical pressure exerted in the silo, the physio–chemical characteristics of the silage crop (Woolford, 1978), consolidation practices, and configuration of silo drainage (Jones and Jones, 1995). This review will focus on pertinent issues relating to crop MC from the time of harvest and thereafter. For consistency, when discussing moisture effects, the reported metric will be MC, rather than dry matter (DM). Dry matter contents were converted to MC assuming that, as percentages, MC = 100% − DM%.

2.1. Moisture content

Silage effluent production typically occurs if the ensiled crop is high in moisture (>75–85%) (Castle and Watson, 1973) over a 30–60 d period, with 90% occurring within the first 20–26 d (Bastiman, 1976; Savoie, 1995). Peak flows typically occur within 10 d after ensiling (Bastiman, 1976; Mayne and Gordon, 1986; Savoie, 1995) due to the time required for plant cell walls to be broken down (Pitt and Parlange, 1987). Being able to precisely predict volume of effluent that will be produced and the timing of peak flows is thus of importance from a management perspective so that farmers can ensure that there is sufficient capacity for containment and treatment.

The pre-ensiled crop MC is influenced by plant factors, weather conditions and mechanical or chemical harvesting treatments (McDonald et al., 1991). There is high variability in reported effluent production rates for different crops of varying MC, however, Jones and Jones (1995) quoted typical values of 0–100 L t^{-1} for corn silage (70–75% MC), 180–290 L t^{-1} for fresh grass or clover (78–83% MC), with wilting grasses to <78% MC preventing leachate formation. After cutting, crops such as alfalfa and grasses may be left in swaths in the field to wilt. Water loss through stomata is highest immediately following cutting and ceases within 2 h due to full stomatal closure (McDonald et al., 1991) after which, moisture loss may continue to occur through the cuticle. Stomatal and cuticular moisture losses during wilting are affected by the swath thickness and weather conditions, the latter controlling evaporation rates (McDonald et al., 1991). Evaporation rates are governed by air temperature, incoming solar radiation, precipitation, wind speed and vapor pressure deficit (Allen et al., 1998; McDonald et al., 1991). During warm, sunny afternoons, a large fraction of solar radiative gains by the swath are dissipated as latent heat fluxes due to high swath–atmosphere vapor pressure deficits and aerodynamic conductance (Allen et al., 1998). Moisture losses are lower on cloudy, cool, humid days, with increases in swath MC possible if there is rainfall. It is important to consider that there is a finite time period that a crop can be left to wilt, and it may not be possible to obtain to optimal MC because of weather conditions.

Corn is not wilted in the filed like grasses and alfalfa. However, plant maturity influences crop MC, with field dry–down of the standing crop occurring as corn ages beyond physiological maturity