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'Shrink' losses in commercially sized corn silage piles: Quantifying total losses and where they occur

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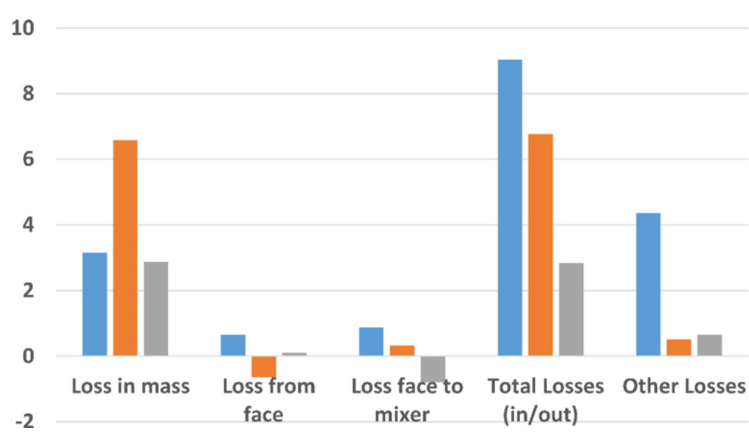
HIGHLIGHTS

- Corn silage piles were used to measure 'shrink' from construction to feedout
- Shrink was wet weight, dry weight (oDM) and oDM volatiles corrected losses (vcoDM)
- Shrink was in silage mass prior to opening, from silage faces and face to feeding
- Shrink was low,
- Aerosol losses from corn silage are a lesser issue than commonly assumed

GRAPHICAL ABSTRACT



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ABSTRACT

Silage 'shrink' (i.e., loss of fresh chopped crop between ensiling and feedout) represents a nutrient loss which can degrade air quality as volatile carbon compounds, degrade surface waterways due to seepage, or degrade aquifers due to seepage. Virtually no research has documented shrink in large silage piles. The term 'shrink' is often ill defined, but can be expressed as losses of wet weight (WW), oven dry matter (oDM), and oDM corrected for volatiles lost in the drying oven (vcoDM). Corn silage piles (4 wedge, 2 rollover/wedge, 1 bunker) from 950 to 12,204 tonnes as built, on concrete (4), soil (2) and a combination (1) in California's San Joaquin Valley, using a bacterial inoculant, covered within 24 h with an oxygen barrier inner film and black/white outer plastic, fed out using large front end loaders through an electronic feed tracking system, and from the 2013 crop year, were used. Shrink as WW, oDM and vcoDM were 90 ± 17, 68 ± 18 and 28 ± 21 g/kg, suggesting that much WW shrink is water and much oDM shrink is volatiles lost during analytical oven drying. Most shrink occurred in the silage mass with losses from exposed silage faces, as well as between exposed face silage removal and the total mixed ration mixer, being low. Silage bulk density, exposed silage face management and face use rate did not have obvious impacts on any shrink measure, but age of the silage pile during silage feedout impacted shrink losses ('older' silage piles being higher), but most strongly for WW shrink. Real shrink losses (i.e., vcoDM) of large well managed corn silage piles are low, the exposed silage face is a small portion of losses, and many proposed shrink mitigations appeared ineffective, possibly because shrink was low overall and they are largely directed at the exposed silage face.

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Abbreviations: DM, dry matter; oDM, oven DM; SJV, San Joaquin Valley;; TMR, total mixed ration;; vcoDM, volatiles corrected oDM; VFA, volatile fatty acids; WW, wet weight.

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1. Introduction

Corn silage has been an important silage crop for a very long time. In our world of over 6 billion people, high use of dairy products has led to large commercial dairy enterprises on which corn silage has become the most important ensiled crop in most developed dairy areas. Losses of corn crop biomass post-harvest during the ensiling period are generally referred to as 'shrink'. Although seldom clearly defined, shrink is the proportion of the fresh crop weight not recovered from the pile as feedable, or sometimes expressed as total, silage.

In addition to being an economic loss to dairy farmers, shrink represents a loss of carbon compounds as leachate from the silage to subsurface aquifers, as seepage to surface waterways, or to the atmosphere as gaseous volatile fatty acids (VFA) and alcohols. As the latter degrade air quality, crop biomass losses during the ensiling period have attracted the attention of various government regulatory agencies, especially water and air districts in California's (USA) San Joaquin Valley (SJV) which are tasked with reducing environmental impacts of dairy farming as a way to create cleaner water and air (Meyer et al., 2015). These regulatory efforts have, in some cases, resulted in semi-mandatory mitigations (i.e., dairy farmers select some mitigations from a longer list in several sections) to reduce silage shrink (Rule 4570; SJV Unified Air Pollution Control District, 2010); mitigations generally based upon limited data of questionable relevance to large commercial silage piles which may or may not actually reduce silage shrink which itself may or may not be a problem of a magnitude equal to that assumed by the regulatory agencies.

Numerous management practices have been suggested to reduce corn silage shrink (Wilkinson and Davies, 2012). These include the use of an inoculant at chopping, building piles on a concrete base, creating high bulk density at silage pile building, use of a plastic cover over the silage pile, use of a plastic film under the plastic cover (with or without enhanced oxygen barrier characteristics), rapid covering of the ensiled mass with the plastic covers, sealing the periphery of the pile with weights, minimizing the area of exposed silage face at feedout, removing the maximum possible horizontal depth of silage from the exposed silage face at feedout, maintaining a 'smooth' silage face, using moveable weight lines along the cut silage face surface of the plastic, only removing as much silage as is immediately needed, use of rotating mechanical or block cutter defacers, and leaving no overnight piles of loose silage. The common feature of all of these potential mitigations is that they will increase costs, but there is little or no published evidence that they reduce shrink in commercially sized corn silage piles.

Shrink losses of corn silage can be defined in many ways. However the most common definition is the proportion of wet weight (WW) fresh crop which is packed into a silage structure (including a pile) and later placed (as silage) into a total mixed ration (TMR) mixer (i.e., fed out). Under this definition, spoilage which is removed and disposed of is shrink. However shrink as defined by governmental air and water regulatory agencies typically does not include spoilage/wastage in shrink since it is actually recovered and not 'lost' into the environment. The interpretive limitation of WW shrink is that much of it may be water, which has no substantive economic or environmental impact. Thus some dairy producers and governmental regulatory organizations also measure shrink on an oven dry matter (oDM) basis. To convert WW shrink to oDM shrink it is necessary to collect many samples of the fresh cut crop at ensiling, as well as many samples of the silage put into the TMR mixer. Besides errors associated with multiple sampling, a serious structural issue of oDM shrink is that its estimation will always overestimate real DM (i.e., non-water) shrink by adding volatile carbon compounds lost during analytical oven drying to the shrink estimate. This is because drying fresh chopped corn crop in an oven will almost exclusively volatilize water, since very few volatile carbon compounds are in fresh chop corn crop, whereas drying corn silage in an oven will volatilize water as well as volatile carbon compounds which will largely be placed into the TMR mixer. Examples of volatile carbon compounds commonly found in corn silage include the VFA acetic, propionic and butyric, as well as the alcohols ethanol, 1,2 propanediol and 2,3 butanediol (Weissbach and Cornelia Strubelt, 2008). Even lactic acid, almost always found in corn silage, will be lost to some extent during oven drying (Porter and Murray, 2001), and the 'oven volatility' of all of these compounds differs among and within compounds in the range of normal oven drying temperatures (Porter and Murray, 2001).

The objectives of this study were to measure shrink as WW, oDM and volatiles corrected oDM (vcoDM) in commercially sized corn silage piles, determine where in the overall process (from chopping the fresh crop to putting the silage in a TMR mixer) that those losses occur, and attempt to identify factors which impact shrink losses, all within the overall aim of quantifying potential impacts of corn silage piles on volatile carbon losses which can effect water and air quality.

2. Materials and methods

Corn silage piles were selected to represent a range of corn silage structures typical of those used on well managed dairy farms in the SJV of California (USA), which is the largest dairy area in the USA containing about 1.5 million lactating dairy cows. There were 4 wedge (i.e., piles with lateral sides and ends with a flat top where the pile sides are not directly packed by tractors due to a relatively acute angle), 2 rollover/wedge (i.e., wedge piles with less acute side angles where tractors pack the entire pile by moving front to back as well as side to side) and 1 bunker structure ranging in size from 950 to 12,204 tonnes (as built), on concrete (4), soil (2) and a combination (i.e., 50% concrete and 50% soil) base (1), on 4 dairy farms, in 2 areas of the SJV all built with use of a bacterial inoculant (various suppliers), covered within 24 h of pile building by professional crews with a 45 μm oxygen barrier polyethylene inner film (Industria Plastica, Mongralese, Italy; trade name 'Silostop') and 125 μm black/white outer plastic (various suppliers) weighted with chains of 1/2 tires, fed out by professional crews on a daily basis using mainly a side-to-side defacing action of a large commercial loader bucket with electronic feeding management software to capture silage weights fed out through the TMR mixer, all from the 2013 crop year.

Due to a general lack of methods appropriate for these large silage structures that would allow us to meet our objectives, most methods had to be developed or adapted for this project. This process took ~1 year in advance of initiating this project. The overall schematic of the experiment is shown in Fig. 1.

2.1. Expressing shrink losses

Weight losses (i.e., silage shrink) were calculated and expressed in three ways. The first was as the WW loss (i.e., using weights of 'as ensiled' fresh chopped crop versus weights of recovered silage); the second was as oDM loss (i.e., using WW multiplied by the 105 °C DM of the fresh chopped corn crop versus 105 °C DM weights of recovered silage); and the third was as the vcoDM (i.e., using oDM of the fresh chopped corn silage crop versus 105 °C DM weights of recovered silage with both fresh chopped crop and silage samples corrected for volatiles lost during oven drying) in the ensiled fresh chopped corn crop versus in the recovered silage. This technique is described in more detail below.

2.2. Measurements and calculations of ensiling process weight losses

2.2.1. Losses in the mass

Weight loss in the silage mass prior to exposure of silage at the pile face was measured utilizing a 'buried bag' procedure with Nylon mesh bags (30.5 $*$ 30.5 cm, 0.32 cm diameter holes divided by 0.16 cm weave; Memphis Net and Twine, Memphis, TN, USA). The bags were modified to create a drawstring around the neck, and marked with a unique number and ~60 cm of colored ribbon attached to the neck. The Nylon bags were filled with ~1.1 kg of fresh chop forage obtained

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