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Total ‘shrink’ losses, and where they occur, in commercially sized silage piles constructed from immature and mature cereal crops

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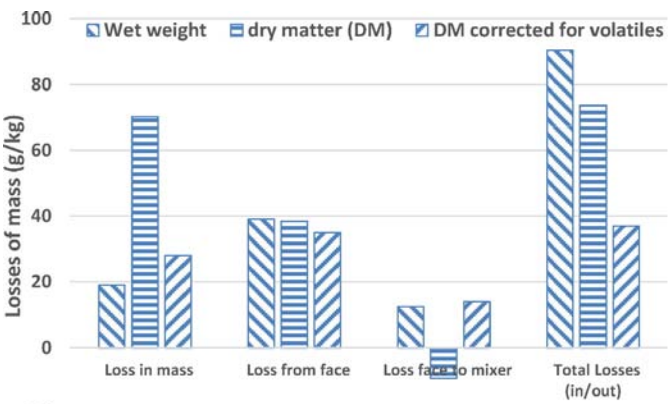
HIGHLIGHTS

- Biomass loss (shrink) was measured in commercially sized cereal silage piles.
- Shrink was as wet weight, dry matter (oDM) and volatiles corrected oDM (vcoDM).
- Immature silages had higher levels of volatile fatty acids and alcohols than mature.
- Aerosol carbon compound losses are little impacted by crop maturity at harvest.
- The vcoDM shrink (i.e., real shrink) losses of all piles were low at ~35 g/kg.

GRAPHICAL ABSTRACT



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ABSTRACT

Silage ‘shrink’ (i.e., fresh chop crop lost between ensiling and feedout) represents losses of potential animal nutrients which degrade air quality as volatile carbon compounds. Regulatory efforts have, in some cases, resulted in semi-mandatory mitigations (i.e., dairy farmers select a minimum number of mitigations from a list) to reduce silage shrink, mitigations often based on limited data of questionable relevance to large commercial silage piles where silage shrink may or may not be a problem of a magnitude equal to that assumed. Silage ‘shrink’ is generally ill defined, but can be expressed as losses of wet weight (WW), oven dry matter (oDM), and oDM corrected for volatiles lost during oven drying (vcoDM). As no research has documented shrink in large cereal silage piles, 6 piles ranging from 1456 to 6297 tonnes (as built) were used. Three used cereal cut at an immature stage and three at a mature stage. Physiologically immature silages had generally higher ($P < 0.01$) levels of total volatile fatty acids (especially acetic acid; $P = 0.01$) and total alcohols ($P < 0.01$) than did physiologically mature crops, suggesting higher carbon compound volatilization potential from immature silages. However expressed as WW, oDM and vcoDM, total shrink (as well as from where in the piles it occurred) was little impacted by crop maturity, and whole pile vcoDM shrink was only ~35 g/kg. Overall, real shrink losses (vcoDM) of large well managed cereal silage piles were relatively low, and a lower potential contributor to aerosol emissions of volatile carbon compounds than has often been assumed. Losses from the silage mass and the exposed silage face were approximately equal contributors to vcoDM shrink. Mitigations to reduce these relatively low emission levels of volatile organic compounds from cereal silage piles should focus on the ensiled mass and the exposed silage face.

Abbreviations: ADF, acid detergent fiber; CP, crude protein; DM, dry matter; NDF, neutral detergent fiber; oDM, oven DM; OM, organic matter; 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

Winter cereal silage is an important silage crop in California, and many other dairy areas worldwide. Loss of crop biomass during ensiling is generally referred to as 'shrink'. Although seldom clearly defined, shrink is the proportion of fresh crop weight which is not recovered from the pile as feedable, or sometimes expressed as total, silage.

The most common definition of silage shrink is the proportion of wet weight (WW) crop packed into a silage structure (including a silage pile) which is not fed out as silage. The interpretive limitation of WW shrink is that much of it is water, which has no substantive economic or environmental impact. Thus some dairy farmers and governmental regulatory organizations also measure shrink on an oven dry matter (oDM) basis. A structural issue of oDM shrink is that it will always overestimate real DM (i.e., non-water) shrink by classing volatile carbon compounds lost during analytical oven drying as shrink because drying fresh chopped cereal crop in an oven almost exclusively volatilizes water, whereas drying silage in an oven volatilizes water as well as volatile carbon compounds which will largely be fed to cattle. This issue can be overcome by analyzing the 'as sampled' and 'oven dried' silages for their volatile components and then arithmetically adding volatiles lost in the drying oven to analytical DM in order to create volatiles corrected oDM (i.e., vcoDM; e.g., Vahlberg et al., 2013).

Silage shrink represents a loss of carbon compounds as seepage to sub-surface aquifers, as runoff to waste storage structures or surface waterways, and/or to the atmosphere as gaseous volatile fatty acids (VFA), alcohols and CO_2, in addition to being an economic loss to dairy farmers due to loss of feedable nutrients. As atmospheric VFA and alcohols degrade air quality, crop biomass losses during ensiling and feedout have attracted the attention of government regulatory agencies which are tasked with reducing environmental impacts of dairy farming, especially water and air districts in California's (USA) San Joaquin Valley (SJV), an area containing ~1.5 million lactating dairy cows (Meyer et al., 2015). These regulatory efforts have, in some cases, resulted in semi-mandatory mitigations (i.e., dairy farmers select a minimum number of mitigations from a longer list) to reduce silage shrink (Rule 4570; San Joaquin Valley Unified Air Pollution Control District, 2010), mitigations generally based upon limited data of questionable relevance to large commercial silage piles where silage shrink, and its composition, may or may not be a problem of a magnitude equal to that assumed.

Cereal crops for silage are harvested at various maturity stages dependent upon objectives. For example, physiologically immature (i.e., prior to head filling) crops create a high fiber (with high rumen fermentability) grass silage, while physiologically mature crops create a lower fiber (with lower rumen fermentability) silage (Van Soest, 1994), but with substantially higher starch levels due to head filling. In-silo fermentation of fiber is accepted to primarily lead to production of VFA whereas in-silo fermentation of starch leads primarily to alcohols (Woolford, 1984). This may be important to air quality as the volatilization potential of most alcohols is higher than that of most VFA (Porter and Murray, 2001), although the volatilization potential of both are much higher than that of lactic acid, which is often quantitatively the most important in-silo fermentation compound. Thus it is possible that ensiled mature (i.e., high starch) cereal crops would contain higher proportions of alcohols thereby creating a higher carbon volatilization potential, with an increased negative impact on air quality.

Our objectives were to measure cereal crop shrink as WW, oDM and vcoDM in commercially sized cereal silage piles, as well as to determine where in the overall process that these losses occur from chopping the fresh crop to putting the silage in a total mixed ration (TMR) mixer. We also assessed the impact of maturity of the cereal crop at harvest on the profile of fermentation end-products created, as well as WW, oDM and vcoDM shrink including where it occurred from pile building to its feedout of silage, all within the overall aim of quantifying potential impacts of cereal silage piles constructed from mature and immature crops on aerosol volatile carbon losses which may negatively affect air quality.

2. Materials and methods

Cereal silage piles were selected to represent silage structures typical of those used on well managed commercial dairy farms in the SJV of California (USA). There were 6 piles ranging from 1605 to 6939 tonnes (as built), on concrete (4), soil (1) and a combination (i.e., 50% concrete and 50% soil) base (1), on 4 dairy farms, in the north and south of the SJV (3 piles each area). All piles were built using a bacterial silage inoculant (various suppliers) added to the fresh chop either in the field (at chopping) or to the trucks prior to unloading, 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 daily by professional crews using mainly side-to-side defacing of a large commercial loader bucket, using electronic feed management software to capture silage weights fed-out, and all from the spring 2014 crop year.

Due to impacts of a long term drought, 3 piles contained cereal (i.e., wheat, triticale, barley or mixtures) harvested with the objective of creating a high fiber cereal silage due to early cutting (i.e., prior to head formation) in order to conserve irrigation water, whereas the other 3 piles contained cereal harvested with the objective of creating a high starch cereal silage due to near normal (i.e., after near complete head formation but prior to senescence of stems and leaves) cereal cutting schedules. Early cut cereals were field wilted 3 to 6 h, whereas late cut cereals were field wiled for <1 h).

As this experiment was part of a larger project which also involved 7 corn silage piles, and that research has been described in detail (Robinson et al., 2016), the descriptions below are abbreviated and readers are referred to this publication for complete method details, and to Fig. 1 for a visual overview of the process.

2.1. Expressing shrink losses

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

2.2. Measurements and calculations of ensiling process weight losses

2.2.1. Losses from the silage mass

Weight loss from the silage mass prior to its exposure at the silage pile face was estimated with a 'buried bag' procedure using Nylon mesh bags filled with ~1.1 kg of fresh chop forage. A subsample of fresh chop crop (corresponding to that put in each buried bag) was preserved frozen from each bag placement hole on the pile filling surface. Buried bags were placed in 5 of the 6 piles in a 14 bag grid (Fig. 2) over time during pile building such that final buried bag placement was in a vertical plane. Bags were extracted from the pile face before air exposure. Upon removal, silage temperature in the center of the bag was measured immediately with an IR Thermometer (Model 561; Fluke, Everett, WA, USA) prior to immediate weighing of the bag and silage contents. A small portion of silage was used to measure pH (Extech Instruments, Nashua, NH, USA). The WW, oDM and vcoDM losses were calculated as weight differences of fresh chop cereal placed into Nylon bags and silage recovered in the bags.

2.2.2. Losses from the exposed silage face

Weight loss (i.e., shrink) from the exposed silage face was estimated by horizontally coring the exposed face twice per pile. Each coring event (Fig. 2) consisted of an initial coring immediately prior (i.e., ~60 min) to