Ensiling is basically a method of crop preservation. Effects on digestibility, palatability and intake potential, and losses of nutrient constituents are each important and of interest in evaluating any ensiling procedure. This discussion, however, will be confined primarily to the quantitative losses of nutrient constituents. The extent of loss of any nutrient is of interest and most constituents, i.e., dry matter, proximate constituents, carotene, and sugar have been measured under some conditions. Even wet weight loss, which has no direct nutritional significance, frequently has been measured. Comparisons of per cent composition in stored and removed silages are easily obtained, but of little value in expressing actual quantitative loss. The amount of dry matter lost during ensiling is frequently cited as a single indicator of ensiling losses, since it is positively correlated with losses of dry matter constituents. While the extent of loss among various fractions is by no means equal or constantly related (30), for the sake of brevity in this discussion losses will be described in terms of dry matter.

Although moisture level of the stored crop and type of storage structure are certainly important variables affecting silage losses, it is often difficult to determine their individual or even combined effect because of interactions with other important factors. The unique effects of plant species, chemical composition, oxygen, physical preparation, preservatives, temperature, and storage rates on silage losses are well documented. These latter factors frequently influence the relative importance of moisture content of the crop stored and storage structure in particular circumstances. Influence of moisture content and storage structure on silage losses are mutually dependent, to the extent that they can most logically be considered simultaneously.

Expressing losses. Total losses may be simply determined as the difference in the amount of material (dry matter, protein, etc.) stored and removed for feeding. Information about the way in which losses may have occurred requires more detailed information.

Dry matter constituents lost during ensiling have three possible escape routes: 1) They may be lost as a liquid (seepage or effluent). 2) They may spoil and become useless as feed, but remain in place. 3) They may be lost as gas (CO₂, NH₃, or CH₄). Losses in seepage and spoilage may be measured by directly weighing and analyzing these fractions. The direct measurement of gas lost from large silos has not been feasible; therefore, this loss is calculated by subtracting the amounts of constituents found as seepage, spoilage, and silage from the amount originally stored. Obviously, gaseous loss is determined with least precision, because it includes the net effect of all the errors experienced in making the direct measurements.

Controlling moisture levels. Early spring-harvested silage crops frequently contain 75–85% moisture. So many problems are created by storing these crops with their full natural moisture content that considerable attention has been given to methods of reducing moisture levels before storage. Reduced average moisture content may be achieved by: 1) wilting; 2) inclusion of a high dry matter additive, and 3) allowing further maturation of the crop. The latter method is generally unattractive, because of lowered feed value of the more mature forage. The second method is employed successfully by addition of dried pulps and feed grains. However, the effects on losses are not strictly attributable to moisture changes, since the average composition of the stored dry matter is also changed considerably.

The optimum harvest stage for corn, as judged by yield and feeding value, coincides with lower moisture contents (25); hence, there is little reason for moisture control. Moisture control in other summer annuals, however, is sometimes desirable.

Expressing moisture levels. Different degrees of wilting are generally indicated by specific terms. Silage stored at 60–70% moisture is termed wilted, and that at 60% or lower, low-moisture silage. The term haylage is usually reserved for low-moisture silage stored in a Harvestore. Such distinguishing terms may be generally useful, but are unfortunate in that they imply that each type possesses a peculiar set of characteristics regarding storage and feeding value. Actually, a better understanding of differences caused by moisture changes may be gained through the concept that lowered...
moisture or wilting tends to impart certain characteristics and that further wilting intensifies these characteristics.

Function of the silo. The silo structure affects losses only to the extent that it furnished protection from air and weather and influences silage density. Architectural terms such as tower, trench, and concrete are very generally related to these functions, and are used in the absence of more objective measurements of air and water infiltration rates.

Seepage Losses

Frequently, the most obvious ensiling loss is that from seepage. Excess water and cell sap is squeezed out by the pressure of the overlying parts of the silage mass. Water is also a product of respiration, fermentation, and oxidation in silage, but does not contribute significantly to the total seepage problem. Thus, seepage loss tends to increase with higher crop moisture levels and taller silos, regardless of the type of structure. Not only does forage of lower moisture content contain less excess fluid but the pressure of the overlying silage is less because of decreased weight.

Some concept of the magnitude of these losses may be gained from existing reports in which the quantity of dry matter lost as seepage is expressed as a per cent of the total dry matter stored. Cornell workers (1, 50) reported losses of 6.8-8.7% from clover-alfalfa stored at 77-82% moisture in 30-ft tower silos. Higher losses, 12 and 13%, were reported by Gordon et al. (19) from 82% moisture grass-clover crops stored in 25-ft silos. The same group found losses of 6.6 and 8.2% after storing orchardgrass at 72 and 75% moisture, respectively (20), and up to 10% in alfalfa stored at 79% moisture (18).

The importance of crop species was demonstrated by losses of 12 and 14% from ryegrass-alfalfa at 87 and 88% moisture, respectively, as compared to 2.2 and 8.0% loss from Tift Sudangrass at 84 and 87% moisture (35). The importance of species and maturity was also indicated by recent Florida work (7), in which fresh forage was mechanically pressed at controlled pressures.

Seepage loss tends to be less in horizontal silos (if protected from precipitation), because of lower vertical pressures. Loss was reduced from 8.2 to 3.7% and from 6.6 to 1.8% by storing direct-cut orchardgrass in sealed bunkers instead of towers (20). However, in unsealed bunkers leaching from precipitation can increase seepage losses an additional eight to ten percentage units above that observed on sealed bunkers (16). The importance of leaching will of course vary with the amount of precipitation and the depth-to-surface area relationship of the structure.

The rather broad range of values cited above indicates that although moisture content is important, losses are affected by other factors. Equations developed by Miller et al., based on moisture content of stored material, appeared useful for predicting seepage loss at the Georgia station (33). However, introduction of data from other sources greatly increased deviations from the regression. Presumably, this was an expression of the effect of other variables.

Seepage loss is practically eliminated when moisture content is reduced to about 68-70% (20, 37, 44, 50). This is most frequently done by field-wilting before storage. Addition of sufficient dry feed to high-moisture forage will also eliminate seepage. The amounts of dry feed usually added, however, result in a reduction but not elimination of this loss (19, 32).

Total Losses

Storing direct-cut forage (about 80% moisture) in farm-sized tower silos has frequently resulted in total dry matter losses of 20-30% (1, 19, 20, 50). These high losses are not related to a particular type of structure but are associated mainly with seepage and extensive fermentation that occurs under the best of conditions. Total losses of 23 and 24% were observed in sealed towers filled with high-moisture alfalfa (18), and losses of 18-29% in red clover silage (27). Occasionally, total losses as low as 14% are reported under such conditions (37). Reports of 25 yr ago indicate that the techniques used for unwilted silage tended to reduce storage losses. First, cutting was often done at a more mature stage, thereby reducing the initial moisture content. Secondly, unwilted forage was subjected to incidental wilting before finally being chopped at the silo. Thirdly, silos were generally smaller and shorter, thus tending to reduce seepage losses (38). Although the extent of total loss observed has varied considerably, it has been great enough to prompt considerable interest in the possible benefits of simply lowering moisture content before ensiling.

Hazards of wilting. Wilting of forage before ensiling is approached with caution, because it results in silage of lower density. Low density, in turn, is conducive to air infiltration, which promotes oxidation and heating, finally evidenced as gaseous and spoilage losses. The relationship of spoilage and gaseous losses is quite variable, although low spoilage losses tend to be associated with low gaseous losses. The relative amounts are no doubt affected by the
amount of air, the period that it becomes available, total length of storage period, and crop composition. The direct relationship of extent of aeration to heating, reduced protein digestibility, and poor chemical quality has been well documented (28, 29, 42, 49). Therefore, as moisture content and density are reduced more reliance must be placed on other means of attaining and maintaining an anaerobic condition.

Forage continues to respire for a considerable period after storage. Fortunately, oxygen is utilized and carbon dioxide produced by this process. Ensiling procedures should be arranged to take full advantage of this phenomenon. Langston et al. (29) measured oxygen in the atmosphere of silage stored at low densities in small silos. Four to five hours after sealing recently stored alfalfa, no more oxygen could be detected. However, when sealing was delayed for 48 hr, residual oxygen persisted for an additional 74 hr. The detrimental effects of prolonged aerobic respiration have also been reported by Kearney and Kennedy (26). These observations indicate that the initial supply of oxygen should not present a storage hazard if the forage can be quickly sealed against entrance of additional oxygen.

In farm practice, a perfectly sealed silo is seldom if ever available. Therefore, it is important to follow procedures which minimize the degree of natural aeration as soon as possible after storage. The damaging effects of delays in filling, on quality and quantity of preserved silages, have been studied by Miller et al. (34). Rapid filling is a means of minimizing the duration of surface-to-air contact as filling progresses. Fine chopping, immature forage, and even distribution are generally recommended as ways of attaining higher and more even density. Storage in a tight, smooth silo and provision of a good top seal also are required. All of these procedures can be followed, but the degree to which they are followed is frequently of primary importance.

Tower silos, wilted silage. In spite of the potential hazards of lowered moisture content, the observed improvements in preservation rates have been gratifying. Since little or no seepage occurs in silage stored below 70% moisture, spoilage and gaseous losses constitute the entire loss. Shepherd et al. (44) reported total losses of 8 to 12% of the stored dry matter in 60-66% moisture forage. These values were obtained in six 10-by-25 ft silos, and without the benefit of top-sealing paper or plastic. However, the silos were repeatedly tramped after filling.

More recently, loss values for wilted silage in conventional silos have been reported by other stations as 8% (37) and 7% (5) when the silage was carefully stored and sealed with weighted plastic. Embry et al. (12) reported a 6% loss from 62% moisture alfalfa stored in a new concrete silo and summer fed as soon as filling was completed. The amount of top spoilage is largely a matter of choice, depending on the care used in sealing. A very successful technique for using a plastic seal has been described by Sprague (47). Voelker and Bartle (48) reported 15 and 30% total weight loss, depending upon the silo condition and top-surface treatment.

Tower silos, low-moisture silage. Interest in and success with much lower moisture levels was reported by Shepherd and Woodward (45) in 1938. Total dry matter losses ranging from 1 to 9% in layers of silage containing 28 to 66% moisture were observed in a concrete silo. Although these results showed the possibility of preserving such forage, the investigators made no attempt to encourage the practice, because of concern for possible losses under less favorable conditions. There was little indication of further interest in low moisture silage until the late 1940's, when the so-called gas tight silo became available. This silo provided a much more complete mechanical protection from air, especially at the surface, than had previously been available. Thus, the potentials of low-moisture silage could be explored with greater confidence and less dependence on the usual precautions for air exclusion.

It is important from a practical point of view to recognize that silos of the very best design will be more or less gas tight, depending largely on the operation and maintenance of the particular structure. A combination of low-moisture (50% or less) and a really tight silo is apparently nearly ideal from the standpoint of reduced losses. Total losses of less than 5% have been reported under such conditions (43). Forage stored at somewhat higher moisture (60-65%), but still under gas tight conditions, lost 4-12% of stored dry matter (18, 43), which is near the minimum observed in conventional silos. Browning (5) observed an average loss of 6% in four gas tight silos filled with Sudangrass and grain sorghum forages at 55% moisture. Voelker and Bartle (48) reported total weight losses of 3.4% as typical of alfalfa stored in gas tight silos at about 50% moisture. Kesler and Cloninger (27) have reported total losses of 0.5 to 6.2% in red clover and timothy stored at 40 and 50% moisture in gas tight silos.

An explanation for the trend toward decreasing losses with decreasing moisture under ideal
storage is offered by differences in the extent of chemical changes. Progressively less acid and ammonium production, but more residual sugar, is observed at progressively lower moisture contents (18) under well sealed conditions. This suggests that fermentation is limited by lack of moisture, whereas respiration and oxidation are limited by lack of oxygen.

Failure to maintain a gas tight condition in a mechanically sealing silo may result in very serious losses (44%), and should not be considered typical of such structures (18) but realized as a possibility.

Success in preserving low moisture silages has not been confined to gas tight silos. Gordon et al. (15, 17) found total losses of 4-12% in eight silos where silage was stored at less than 60% moisture in 10-ft-diameter silos. Some localized spoilage (3-6%) was observed in all of these silages, which were manually unloaded, and was included in the total loss. Gaseous losses ranged from 1-12%, and the separated spoilage accounted for the somewhat lower efficiency as compared to ideal gas tight conditions. Another silo, however, lost 16% of stored dry matter and still another showed a 24% spoilage loss. The latter silage was stored at 43% moisture in a 40-ft silo that leaned 10-12 in. from bottom to top. The nonvertical position may have contributed to aeration and spoilage by a poor silo-wall-to-silage content as settling progressed.

Alfalfa grass stored at 48% moisture in a good concrete silo lost 9% of the stored dry matter in gas and spoilage, according to Kesler and Cloninger (27). Shepherd et al. (43) also concluded that top and side spoilage represented the major differences between the two types of silos for low moisture storage. Embry et al. (12) observed 4.2% loss in 42% moisture alfalfa stored in a concrete tower. Feeding commenced immediately after filling and continued through the summer. A subsequent observation at the South Dakota station (51) showed a 12% dry matter loss under similar conditions, except for storage at 38% moisture.

As a deviation from the primary subject of discussion, the occasional associations of low moisture and decreased protein digestibility should be mentioned. Observations of this type have been made at Mississippi (6), Wisconsin (41), and Beltsville (18). The work of Wieringa et al. (49), showing a positive association of oxygen, temperature, and low protein digestibility, indicates that inadequate oxygen exclusion might be involved. However, the necessity of oxygen for this reaction has not been proven and Hale et al. (22) have suggested that the high ambient temperature of Arizona may directly reduce protein digestibility.

Singularly poor results are sometimes observed with low-moisture silage in conventional towers. Perry et al. (39) observed a 25% loss in 50% moisture legumes, in addition to the complete loss of 19 T of direct-cut forage applied as a top seal. Their conclusion, that sealing procedures are extremely important, can hardly be disputed, nor should these results be considered typical.

**Bunker and trench silos.** Effects of moisture on losses in horizontal silos have received less attention than with vertical storage. Losses of about 30-50% (16, 21, 48), observed in unsealed or poorly sealed horizontal silos, were sufficient to discourage much thought of increasing the difficulties of such storage by willing. Until the advent of low-cost plastic film, the sealing materials available required so much labor to be effective that bunker or trench storage was reserved for emergencies or very large silos.

Plastic film properly applied has effectively changed the outlook for horizontal storage, although poor sealing low preservation can still be attained. Total losses of 10-20% in bunker-stored, direct-cut, high-moisture grass have been as low or lower than expected for similar forage stored in towers (16, 20). Reduction of seepage loss through less vertical height, and elimination of surface spoilage as a major source of loss, have been primary contributing factors.

Rather limited work has indicated that wilted and low-moisture silage may be preserved in a bunker at efficiencies approaching those found in conventional tower storage. Dry matter losses of 13 and 9% in 68 and 33% moisture hay-crop forage were observed with carefully applied side and top seals (17) and a continuous harvesting period. Such favorable conditions are not always obtained and the same group reported losses of 28% in 58% moisture orchardgrass when filling was delayed by rain and a carefully placed seal was subsequently damaged (9). Brown and Kerr (4), using 50% moisture hay-crop forage, observed about 12% total loss in polyethylene-lined and covered trench silos and 70% loss in unlined, uncovered trenches.

The sealing technique is obviously very critical in determining the extent of losses. Among the presently available sealing materials, plastic sheeting (properly weighted) is most satisfactory. It has been far superior to thick layers of limestone, earth, or sawdust (3, 31, 36) for reducing total losses of surface losses. Evaluation of a sealing material on the basis of
surface spoilage alone may be misleading, because effects on gaseous and seepage losses are ignored (8, 10, 36). A roof only was of very little value for loss reduction under New Zealand and U.S. conditions, yet it is encouraged by Government subsidy in the United Kingdom (10, 36). It has also been demonstrated that plastic without a continuous weighting material, such as sawdust or forage, is of little value, since air leaking through a small puncture may affect the entire surface (21, 23, 24).

**Stack silos.** Stack silos present the maximum opportunity for high losses, because of their configuration. It is possible, however, to completely eliminate surface spoilage with a plastic covering, by a procedure described by Sprague (46). He found that silage stacked inside a plastic sleeve closed at the top was preserved with essentially no spoilage. Gaseous losses were not reported. Hodgson et al. (24) reported about 92% total recovery by a similar procedure, using corn and grass silage. Experience at Beltsville (16) was not as successful, with observed losses being 21%, none of which was spoilage. The basic disadvantages of sealed stacks are relatively high labor requirements and difficulties in protecting against the effects of small leaks. Shallow stacks (1–4 ft deep) built directly on the ground can be very successfully sealed with a weighted plastic sheet. This type of structure requires a ground sheet on sandy soils, to prevent air entering from the ground (13).

Low-moisture silage will develop heat and mold as a result of poor sealing or slow feeding. This problem may be more acute in plastic-sealed stacks. Some attention has been given to fungicides as a remedy for these problems. A preliminary investigation showed that at least one fungicide might be useful for this purpose (14). Fungicidal materials should be investigated further, to determine their place as an aid to ensiling when less than optimum conditions are provided.

A modification of the plastic-sealed stack is the vacuum stack. In these silos stacked forage is consolidated by creating a vacuum under a plastic canopy. Interest in this procedure has centered primarily in Europe and more recently in New Zealand (2, 11). The plastic must be carefully applied, to create a vacuum, and the resulting silage is well-preserved. The author has not been able to determine, from the literature, the relative importance of the sealing and evacuation. Certainly, the high density obtained by vacuum would be desirable in most silos, if it could be achieved conveniently.

**General Observations**

The large body of data concerning losses in silos, much of which has not been cited, supports some rather general statements concerning the expected effects of moisture and structure on silage losses. If one assumes that the structure provides a very good seal, total losses of 20% or more should be expected in high-moisture silages. This silage has the combined potential disadvantage of highest seepage loss and highest fermentation loss. As moisture content is decreased down to the 50% range, total losses will decrease to a minimum of 2–5%, which results from no seepage, no spoilage, and a very limited amount of fermentation and respiration.

The observed deviations from the above general trends are large, because of occasional inadequacies in all types of structures. Gaseous losses are increased by increasing permeability of the silo structure to air. This is particularly true in forages of lower moisture content, which are less dense and readily oxidized. Sufficient air permeability results in visible spoilage, adding further to the total loss. A basic disadvantage of low moisture silage is a relatively low specific heat. Thus, a given amount of air and oxidation results in a relatively large temperature increase.

The vast number of combinations of moisture content of crop, permeability of silo and silage to air, and length of storage period produces a broad range of observed losses. The prospect of reducing total losses below 5% by reducing moisture content below 50% is not very attractive. A very limited fermentation and gaseous losses approaching zero are theoretically possible. Practically, however, minor air leaks become increasingly important and an increase in oxidative losses may result in a net increase in total losses. Field losses could also be expected to increase sharply, below 50% moisture.

Protection from atmospheric oxygen is most easily, but not necessarily, obtained in a rigid, mechanically sealing silo and, at the other extreme, obtained with stacks only by careful attention to sealing techniques and management. One can, therefore, expect observed storage losses to differ as much within moisture levels and structures as between them. Management is often the somewhat elusive explanation for relative success in silage preservation, just as it explains the degree of success in several other aspects of agricultural production.

Technical explanations of small differences in preservation await more accurate control and monitoring of physical and chemical conditions within the silage mass. Meanwhile, much progress on the farm can be made toward better
crop preservation by conscientious application of the established principles of ensiling.

References


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