Nutrient Recovery and Chemical Changes in Oat Silage

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The conversion of carbohydrates to organic acids is the primary change occurring in silage fermentation. The factors affecting the efficiency of this conversion were studied in eight silos of oat silage. The recovery of organic acids was consistently affected by type of fermentation and preservative used. In silos having a lactic acid type of fermentation, 1 pound of organic acid was recovered for each 1.87 pounds of carbohydrates lost. The corresponding recovery of acids in silage with a low lactic acid fermentation was 1 to 2.80. Ground snap corn resulted in a recovery of 1 pound of organic acid for each 1.96 pounds of carbohydrates lost, while with sodium metabisulfite the recovery ratio was 1 to 2.87.

THE INCREASING USE of oat forage as a silage crop has resulted in continuing efforts to determine factors affecting the quality of this silage. Oats have many attributes which make them nearly ideal silage crops—e.g., at a given stage of maturity, they are usually higher in dry matter and lower in protein than most grassland crops. If properly handled, these characteristics result in proper conditions for silage fermentation.

In desirable silage fermentation, the plant cells produce carbon dioxide, which results in an anaerobic condition essential for lactic acid production; volatile acid production is limited; and lactic acid production is encouraged. These events are aided by an available supply of carbohydrates, the exclusion of air, and a temperature ranging from 80° to 100° F.

In silage making, the losses may be divided between those which are unavoidable—normal losses in fermentation and seepage—and those which may be avoided—excessive losses due to poor ensiling techniques. Barnett (2) has listed several possible routes by which carbohydrates or protein can be converted to volatile acids. Theoretically, fermentation losses could be small if the fermentation were confined to lactic acid formation. The simple enzymatic conversion of hexoses or disaccharides to either lactic or acetic acid can be accomplished with little loss in combustible energy. When poor techniques are followed in silage making and the proper conditions for lactic acid formation are not created, the end-products may consist largely of volatile acids which may be produced with combustible energy losses of 20 to 40% (2). Losses of this magnitude are due to poor packing of the silage with a resulting aerobic type of fermentation which prolongs the time required to lower the pH to a point low enough to prevent further fermentation. Using the breakdown reactions listed by Barnett (2), extreme cases of aerobic fermentation or lack of sufficient carbohydrates may result in calculated energy losses approaching 75% when protein is converted to volatile acids. (These calculated losses refer to that portion of the carbohydrates or protein actually converted to acids and not to the total material ensiled.) Allred *et al.* (1) ensiled direct cut forages in 10 × 30 foot silos and reported an average loss of 6.3% of the ensiled dry matter in seepage, 5.6% in spoilage, and 15.4% from fermentation or a total loss of 27.3%. Thus with high moisture forages, dry matter losses may be quite high although good silage making techniques are followed.

As part of the silage evaluation program at this station, studies were initiated on the effects of stage of maturity at cutting and the use of preservatives on the subsequent nutrient losses and feeding value of oat silages. Silages made in 1956 and 1957, and the forages from which the silages were made, are the subject of this paper.

No previous work on storage losses with direct cut oat silage was found in the literature. General problems of and methods for silage making were reviewed by Barnett (2). Watson and Ferguson (7) worked with several sizes of silos and concluded that "where nutritive losses are to be measured, the silo should hold at least 8 to 10 tons of silage."

Materials and Methods

Silage. Eight silos of oat silage are included in the balance study. Silages 3-57 and 6-57 were cut at the boot stage, silages 2-57, 5-57, 4-56, and 1-56 at the prebloom stage, and silages 4-57 and 2-56 at the milk stage. Silages T-56 (sudan grass cut at boot stage), 7-56 (barley-prebloom), 5-56 (oats, dough stage), and 6-56 (corn) were included in the chemical change studies. Where used, sodium metabisulfite was added at the rate of 8 pounds per ton, and ground snap corn at 200 pounds per ton of fresh forage ensiled.

The forages were ensiled in 20-ton upright silos equipped with instruments for continuous temperature recording and measuring seepage losses. Arlington oats were fall-seeded and ensiled in April and May of the following year. The forage was cut with a direct-cut forage harvester and delivered to the silos in trucks. Each load of silage was weighed, and preservatives were added at the silo. Forage samples were collected from each load of fresh cut oats and taken immediately to the laboratory for moisture determination by the toluene distillation technique of Perkins (5). Aliquot samples were dried in forced air at 70° C. for chemical analysis. The silos were filled at a rate calculated to duplicate filling 100-ton silos, and packing was delayed or increased to obtain silage temperature between 80° to 100° F. This effort to control silage temperature was, in effect, an effort to secure a rapid production of lactic acid and a rapid fall in pH in order to prevent excessive losses due to fermentation and to the formation of large quantities of volatile acids. The silos were capped with tar paper covered with 12 to 18 inches of wet sawdust.

Silage Analysis. The silos were opened and silage fed in feeding trials. Each silo was emptied in about 5 weeks after opening. All silage was weighed out of the silo, and 5-pound samples were taken each Monday, Wednesday, and Friday for laboratory analysis. In addition to the forage dried for analysis, aliquot samples were frozen for the same analyses performed on fresh materials.

Dry matter was determined by toluene distillation, pH, and free acidity on a 2 to 1 boiling water extract of the silage, and proximate analyses were made on dried silage samples. Hydrolyzable carbohydrates were determined on dry materials by the sulfuric acid–phenol technique outlined (2).

Organic acids were liberated from the fresh silage, and the total acids were titrated according to the method of Pucher, Vickery, and Wakeman (6) with the modifications noted below. The gas-liquid chromatographic method of James and Martin (4) was used for the quantitative determination of the volatile fatty acids present.

Fifty-gram samples of silage were extracted with ether for 3 days, after which time the ether containing the volatile fatty acids was dried with anhydrous sodium sulfate and made up to a volume of 250 ml. with freshly distilled ether. A recovery of 87.6% of acids was obtained from known samples. A 25-ml. aliquot of the sample was added to 10 ml. of 0.1*N* sodium hydroxide, mixed thoroughly to ensure formation of the sodium salts, and the ether was evaporated. Enough distilled water was added to make a total volume of 100 ml. before the sample was titrated electrometrically, between pH 8.45 and pH 2.6, with either 0.143*N* or 0.0358*N* hydrochloric acid. The total acid value was calculated from the titration within these pH limits.

The rest of the ether extract, 225 ml. was evaporated to a volume of 1 to 2 ml.—depending on the concentration of acids present—and the volatile fatty acid concentration was determined by gas-liquid chromatography with a Perkin-Elmer Model 154 Vapor Fractometer equipped with a 4-foot 1/4-inch outside diameter stainless steel column containing a mixture of 33 1/3% w./w. stearic acid on Celite 545. It was operated at 120° C. with helium as the carrier gas.

The concentrations of the volatile acids were obtained by integration of the areas of the acid curves and multiplication by factors determined for concentration per unit area from curves made with known concentrations of the acids. These factors and their corresponding coefficients of variation are shown in Table I.

Lactic acid was calculated as the difference between the total acid minus the volatile acids.

Recovery of nutrients was calculated as the per cent of ensiled nutrients available for feeding. The ratio of acids formed per pound of hydrolyzable carbohydrates lost was recorded on a per ton of silage basis as there were slight differences in quantity in each silo.

Table I. Factors Used for Calculation of Volatile Fatty Acid Concentration

Acid	Meq. Acid/Sq. Cm.	Coeff. of Variation
Acetic	4.14×10^{-4}	0.93
Propionic	3.72×10^{-4}	2.03
Butyric	5.38×10^{-4}	5.93

Table II. Samples Required to Fix Specified Fiducial Limits ($p < 0.01$) from Sample Means

Item	Specified Fiducial Limits	Number of Samples Required
Dry matter	±1.5%	15
pH	±0.1	12
Free acidity	±15 ml. 0.1*N* NaOH	13

Table III. Chemical Composition of Forages and Resulting Silages

(Dry matter basis)

Silage	Item	Crude Protein	Ether Extract	Crude Fiber	N.F.E.	Ash	Hydrolyzable Carbohydrates
3-57	Forage	10.42	2.29	22.23	59.80	5.26	29.74
	Silage	11.93	4.23	27.00	51.55	5.29	14.28
6-57	Forage	10.24	2.07	22.58	59.77	5.34	38.83
	Silage	10.47	4.38	35.58	43.43	6.14	3.76
2-57	Forage	10.35	2.25	30.36	52.50	4.54	23.28
	Silage	10.12	3.24	36.36	44.45	5.83	11.06
5-57	Forage	9.94	2.32	28.91	54.40	4.43	29.04
	Silage	10.30	3.59	29.87	52.06	4.18	22.60
4-56	Forage	8.67	2.86	21.42	62.65	4.40	26.60
	Silage	9.31	8.03	23.59	54.41	4.66	15.10
1-56	Forage	8.52	2.80	25.58	57.82	5.28	23.68
	Silage	10.71	3.76	29.11	47.27	9.15	15.93
4-57	Forage	8.67	2.86	21.42	62.65	4.40	26.60
	Silage	9.31	8.03	23.59	54.41	4.66	15.10
2-56	Forage	8.10	2.96	30.45	53.99	4.50	16.99
	Silage	9.20	5.66	30.90	46.94	7.30	7.37
T-56	Forage	13.66	4.69	25.09	49.21	7.34	...
	Silage	14.27	7.06	30.58	45.55	7.06	...
7-56	Forage	9.10	2.51	28.37	55.86	4.16	...
	Silage	9.52	3.19	34.14	45.70	7.45	...
5-56	Forage	7.02	3.19	31.10	54.32	4.37	...
	Silage	7.58	4.22	35.02	47.33	5.85	...
6-56	Forage	6.81	3.41	21.01	64.42	4.34	...
	Silage	8.38	3.81	21.06	61.23	4.85	...

Table IV. Relationships between Chemical Composition of Forage and Resulting Silages

Item	Correlation (r)	Linear Regression
Crude protein	0.936[a]	$Y = 1.96 + 0.877X \pm .29$
Ether extract	0.574[b]	$Y = 1.80 + 1.252X \pm .67$
N.F.E.	0.697[b]	$Y = 4.00 + 0.79X \pm .36$
Crude fiber	0.727[a]	$Y = 5.59 + 0.939X \pm .40$

[a] Significant at 1% level.
[b] Significant at 5% level.

Results and Discussion

Sampling Accuracy. Sampling several tons of a heterogeneous silage presents certain difficulties familiar to workers in the field. As the silos were being emptied at an approximate rate of 3% per day, sampling rates were established to secure aliquot samples from approximately each 6% of the silo or a total of 16 samples from each silo. On the basis of the observed variance in dry matter, pH, and free acidity measurements, sample numbers were calculated in terms of fiducial limits representing reasonable accuracies in silage work. These data are shown in Table II. A mean of 16 samples per silo provided an accurate sample and lend further weight to the accuracy of the calculations used in determining nutrient losses.

Changes in Chemical Composition. The chemical composition of the forages and resulting silages are presented in Table III. As the silage fermentation process results in the conversion of soluble carbohydrates to lactic and volatile acids, the normal changes should include a decrease in nitrogen-free extract and an increase in ether extract. Theoretically the percentage of crude fiber and protein should increase by concentration. In the 12 silages under study, the mean changes in percentage of the nutrients were: crude protein, +0.83; ether extract, +1.71; N.F.E., −5.64; and crude fiber, +4.02. The correlations between forage and silage composition and the regressions which describe the changes are shown in Table IV. The average changes reflect an undesirable change in feed composition. The most frequently encountered nutrient deficiency in forages is an energy deficiency, thus any change which lowers the readily available carbohydrate must be considered as undesirable. Such a change is normal in silage and constitutes a normal loss unless it occurs as the result of poor techniques. Current knowledge

Table V. Preservation of Nutrients and Formation of Acids in Silage

(Dry matter basis)

	Oats							
	Boot Stage		Prebloom				Milk	
Silage No.	3-57	6-57	2-57	5-57	4-56	1-56	4-57	2-56
Preservative[a]	*C*	*S*	*S*	*C*	*C*	*S*	*N*	*S*
Total forage ensiled (tons)	16.23	19.00	15.13	12.28	16.76	19.40	10.70	15.88
Forage dry matter (%)	27	25	28	30	28	25	35	29
Silage dry matter (%)	28	20	25	29	30	25	29	26
Silage pH	3.8	4.1	4.1	3.9	3.7	4.3	4.0	4.1
Preservation of nutrients (%)[b]								
Wet material	72.4	69.4	84.2	89.6	87.3	85.6	96.0	88.8
Dry matter	76.0	54.2	75.9	84.9	93.8	86.3	79.0	79.0
Crude protein	87.1	55.4	74.2	87.9	100.7	108.5	88.6	89.3
Ether extract	140.4	114.7	109.3	131.2	263.4	115.8	105.1	151.8
Crude fiber	92.3	85.4	90.9	87.8	103.3	98.2	90.4	80.1
N.F.E.	65.5	39.4	64.3	81.2	81.5	70.5	68.8	68.6
Ash	76.5	62.4	97.4	80.0	99.4	149.5	87.5	128.2
Hydro. carbohy.	36.5	6.6	36.1	49.1	53.3	58.0	22.6	34.2
Pounds of acid formed (per ton silage)								
Acetic	2.69	1.75	10.93	0.46	7.61	0.57	4.37	1.82
Propionic	....	0.03	....	0.05	....	....	....	....
Butyric	....	0.11	....	....	....	....	....	....
Lactic[c]	48.47	45.27	41.82	24.72	64.38	27.43	52.98	40.76

[a] *N* = none, *C* = ground snap corn, *S* = metabisulfite. [b] Total spoilage did not exceed 100 pounds in any silo. [c] That portion of the acids which was nonvolatile.

does not permit a fine line of distinction to be drawn between avoidable and unavoidable losses. The significance of the change in ether extract will be discussed later. The large error of estimate for ether extract and N.F.E. indicated that the fermentation process is not a simple transformation but rather an unpredictable process.

Recovery of Nutrients. Data on the recovery of individual components of the parent material are shown in Table V. Nutrient preservation increased with increasing dry matter content of the forage and stage of maturity of the crop. This trend was not entirely due to differences in seepage loss. Only three of the silages seeped enough to make this loss a factor (silos 1-56, 3-57, and 6-57). Unfortunately, a broken line prevented the collection of seepage on silage 6-57 as the total loss in this silo was obviously great. The average dry matter seepage loss on silo 3-57 was 1.2% and that on 1-56 was 1.9%. The data indicate that silage subject to seepage losses are also subject to high fermentation losses, which may be due to differences in available carbohydrates and higher protein and ash contents, which increase the buffer capacity of the silage. The effect of preservative was quite pronounced. The average recovery of silage dry matter when ground snap corn was added was 85%, and the corresponding value for sodium metabisulfite was 72%. The data available from these studies do not explain many of the changes found in the silages.

The item of primary interest was the relative efficiency with which the fermentable carbohydrates were recovered as organic acids as, on the average, 88% of total dry matter losses were from this fraction. Barnett (*2*) cited several experiments in which lactic acid was produced with little or no production of carbon dioxide. Such a conversion is theoretically possible if the substrate consists of hexoses and/or disaccharides. In large silos, so simple a reaction would not be expected to occur as 12% of the dry matter losses include protein and other carbohydrates. In addition to lactic acid formation, volatile acids are also formed, and in some instances lactic may be attacked, and acetic or butyric acid may be formed with a resulting loss of nutrients. The data in Table V would tend to indicate that a less efficient fermentation occurred in these silos. The mean rate of recovery in the eight silos was 2.27 pounds of hydrolyzable carbohydrates per pound of organic acids. The factors which consistently altered this ratio were the preservative used and the degree of lactic acid fermentation. Ground snap corn as a preservative resulted in a mean conversion rate of 1 to 1.96; and sodium metabisulfite gave a mean rate of 1 to 2.87. In the four silos, with the lowest percentage of lactic acid (mean 7.40%), the conversion rate was 2.80 pounds of hydrolyzable carbohydrates per pound of acid while the corresponding rate for the four high silos (mean lactic acid, 12.70%) was 1.87 pounds.

As the volatile and lactic acids formed are usable end products of rumen fermentation, the conversion of carbohydrates to acids may not represent a loss in feeding value of the silage dry matter. Bentley *et al.* (*3*) fed mixtures of acetic and lactic acids to fattening lambs and found feed replacement values of 3 to 9 pounds per pound of acid. Should this hold true with silage acids, one could argue that the feeding value was not lowered by the production of these acids in silage. Silage feeding trials do not permit this factor to be studied directly as other changes in forage composition cannot be separated from the acid effect. Recent preliminary trials at this station have indicated that, in the artificial rumen, silage supports a less active fermentation than the forage from which it was derived. Future rations may include rumen stimulating factors to overcome this weakness and thus increase the efficiency with which silage is utilized. The carbohydrates lost in seepage and that portion lost as gases in fermentation do represent a direct loss of energy and may be quite serious as energy is usually a limiting factor in forage utilization.

Literature Cited

(1) Allred, K. R., Kennedy, W. K., Wittwer, L. S., Trimberger, G. W., Reid, J. T., Loosli, J. K., Cornell Univ. Agr. Exp. Sta. Bull. **912,** 1955.
(2) Barnett, A. J. G., "Silage Fermentation," Academic Press, New York, 1954.
(3) Bentley, O. G., Johnson, R. R., Royal, G. W., Deatherage, F., Kunkle, L. E., Tuznik, W. J., Bell, D. S., Ohio Agr. Exp. Sta. Research Bull. **774,** 1956.
(4) James, A. T., Martin, A. J. P., *Biochem. J.* **50,** 679 (1952).
(5) Perkins, A. E., *J. Dairy Sci.* **26,** 545 (1943).
(6) Pucher, G. W., Vickery, H. B., Wakeman, A. J., *Ind. Eng. Chem., Anal. Ed.* **6,** 140 (1934).
(7) Watson, S. J., Ferguson, W. S., *J. Agr. Sci.* **27,** 67 (1937).

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