Changes in gas composition in corn silages in bunker silos during storage and feedout

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Weinberg, Z.G. and Ashbell, G. 1994. **Changes in gas composition in corn silages in bunker silos during storage and feedout.** Canadian Agricultural Engineering **36**:155-158. The objective of this project was to study gas composition within silages during storage and unloading. For that purpose, changes in CO_2, N_2, and O_2 within four commercial corn silages in bunker silos were monitored during storage and unloading. On the day of filling, five plastic net bags containing the same chopped crop as the remainder of the silage, pipes for gas sampling, and thermocouples were buried in the center of each silo. In two bunkers, two such sets were installed 10 m apart. Gas samples and temperature measurements were taken routinely at two-week intervals during storage and more frequently as the unloading face approached the bags. When the face reached the bags, the bags were retrieved and the contents analyzed in the laboratory. The results include chemical analyses of the various silages, dry matter losses, and the percentages of CO_2, N_2 and O_2 during storage of the silages and feedout. Low CO_2 and high N_2 levels might indicate air penetration into the silage. In general, CO_2 levels in the center of the sealed silages were 60-90% and these were higher than the CO_2 levels in the top layer (20-40%) reported in a previous study. In two bunkers they remained at a high level (>70%) until the unloading face was only 1 m away. The data presented here could be useful in further studies of aerobic deterioration of silages.

Le but de cette étude était d'observer la mutation des gaz durant l'ensilage et la distribution. A cet effet les mutations de CO_2, N_2, et O_2 dans quatre silos bunker commerciaux ont été observées durant l'ensilage et la distribution. Le jour de remplissage, cinq sacs en plastique contenant le même mais coupé comme le reste du silo, plus la tuyauterie nécessaire pour l'échantillonnage des gaz et des thermocouples furent enfouis au centre de chaque silo. Dans deux citernes, deux systèmes semblables furent installés à dix metres d'écart. Les échantillons de gaz et les prises de températures furent conduit routinement toutes les deux semaines durant l'ensilage, et plus fréquemment lorsque le système de livraison se rapproche au frontal des sacs. Quand le frontal en arrivait aux sacs, ceux-ci furent analysés au laboratoire. Les résultats comprennent l'analyse chimique des divers ensilages et la perte de matière sèche et le pourcentage de CO_2, N_2 et O_2 pendant l'ensilage et lors de la distribution. Un niveau bas de CO_2 et un niveau haut des N_2 pourraient indiquer une pénétration d'air dans l'ensilage. En général, les niveaux de CO_2 au centre des silos (60-90%) furent plus haut que ceux observés à la partie supérieure (20-40%) d'après une étude précédente; alors que dans deux citernes, le niveaux de CO_2 restait haut jusqu'à un mètre de l'apparition du système de livraison. Les résultats présents, pourraient être utiles lors d'une étude future sur la détérioration aérobic de l'ensilage.

INTRODUCTION

Conservation of forage crops by ensiling is based on natural fermentation, whereby lactic acid bacteria convert water-soluble carbohydrates into lactic acid under anaerobic conditions. As a result, the pH decreases and the moist forage is preserved. When silage is exposed to air, it is prone to deterioration because air promotes the activity of aerobic microorganisms (Woolford 1990). This activity results in dry matter (DM) losses which, within one week, may exceed the storage losses of several months (McGechan 1990). Therefore, aerobic deterioration of silages is considered a serious problem, and many research efforts are directed to learning the processes which are involved and to finding means to minimize the losses caused by aerobic deterioration (e.g. Ohyama et al. 1980; Spoelstra et al. 1988; Weinberg et al. 1993).

Silage is exposed to some air during storage, because sealing is not hermetic, and more so during feedout. In experiments performed with modified atmospheres, oxygen levels as low as 1% resulted in spoilage of silage (Lisker et al. 1989). Honig (1991) discussed the gas exchange processes which lead to air ingress into the silage. These processes comprise diffusion and gas flow due to differences in specific weight between the major fermentation gas product, CO_2, and air. Diffusion depends on concentration differences between the inner and outer regions of the silage and on the permeability of the silo walls, sealing cover, and of the forage (Weise et al. 1975, cited by Honig 1991). The porosity of the silage depends on compaction in the silo and this is a function of DM content and compacting method and machinery, forage structure, and chopping length. A DM density above 200 $kg \bullet m^{-3}$ is necessary to bring gas flow down to 20 $L \bullet h^{-1} \bullet m^{-2}$ (Honig 1991).

Under farm conditions, silages vary with respect to their compaction, rate, and method of unloading (silage cutter or front unloader), and hence extent of air penetration. Since even low levels of oxygen may trigger the detrimental activity of aerobic microorganisms, the onset of aerobic deterioration within a silage may start even before the face reaches a specific layer, depending on air ingress. The purpose of this project was to monitor air penetration into commercial corn (maize) silages in bunker silos in Israel (subtropical climate) by measuring changes in gas composition within the silages during storage and unloading.

MATERIALS AND METHODS

Four bunker silos on kibbutz farms near The Volcani Center (less than 25 km away) were chosen for the experiments. The dimensions of the bunkers were approximately 30x7, 30x7, 25x10 and 30x5 m, by about 3 m high. On the day of filling a silo, five plastic net bags, each containing 5 kg of fresh whole chopped corn identical to the rest of the silage, were buried in the center of each silo. Thermocouples and 5-mm plastic tubes were connected to the bags with connections across the walls for routine temperature measurements and gas sampling. Bunkers 1 and 2 had two sets of bags, thermocouples and tubes, placed 10 m apart, referred to as "forward" and "backward". Temperature recordings and gas samples were taken routinely every two weeks during storage and more frequently as the unloading front approached the bags. Gas samples were taken with a 50 mL syringe. The tubes were flushed by withdrawing 300 mL gas before taking the sample for analysis. The syringe was then stoppered and brought to the laboratory immediately. Gas composition included the determination of carbon-dioxide, oxygen and nitrogen and was performed with a Tracor 565 gas-chromatograph equipped with a thermal conductivity detector and fitted with a dual column maintained at 50°C: Poropak Q for CO_2, and molecular sieve 5A, for N_2 and O_2.

When the unloading front reached the bags, they were retrieved and brought to the laboratory for chemical and microbiological analyses. Chemical analysis included determination of DM, pH, ash, and water-soluble carbohydrates (WSC). Dry matter was determined by oven drying at 60°C for 48 h. Ash in the dry samples was determined in a muffle oven at 550°C for 2 h. pH was measured on the filtrate of 10 g of wet material blended for 5 min with 90 mL of distilled water. Water-soluble carbohydrates were determined by the phenol-sulfuric acid method, according to Dubois et al. (1956). Dry matter losses were calculated from weight and moisture in the fresh and the ensiled bags. Microbiological analyses were performed on samples from three silages and included total aerobic counts on Bacto Nutrient agar (Difco), yeasts and molds on Jarvis agar. The Petri dishes were incubated at 27°C for 7 days before the colonies were counted.

RESULTS AND DISCUSSION

Seasonal changes in the ambient temperature were reflected in the temperature within the silages, and ranged from 39-41°C in summer (July-September) to 31-36°C in winter (December-February). No heating was observed when the unloading front approached. This agrees with the relatively low DM losses (Table II).

Changes in gas composition in the four silages are given in Figs. 1-4. In these figures, the Roman numbers on the X-axis indicate months of storage until the start of unloading. Table I includes the unloading rates of the silages. A high initial CO_2 concentration in the silage indicates good sealing; it results from plant respiration and aerobic activity which use up the O_2 within the silage and from anaerobic fermentative activity. The CO_2 produced displaces the N_2 which is part of the air which was present within the silage in the beginning. When air penetrates into the silage during storage, the oxygen in the air is also converted into CO_2. Therefore, O_2 always appears at a very low concentration. Changes in nitrogen levels form a mirror image of the CO_2 levels. A high percentage of nitrogen can serve as an indicator of air penetration.

In bunker 1, CO_2 levels at the forward set decreased from 85 to about 50% during storage and then decreased gradually to 30% with fluctuations, indicating intensified aerobic activity. In the backward set, CO_2 levels remained relatively high (80%), decreased gradually with the progress of feedout, and

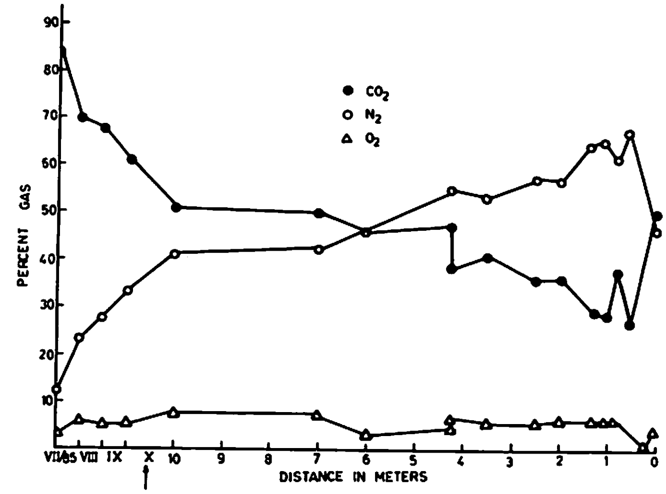

Fig. 1a. Changes in gas composition in bunker 1 - forward.

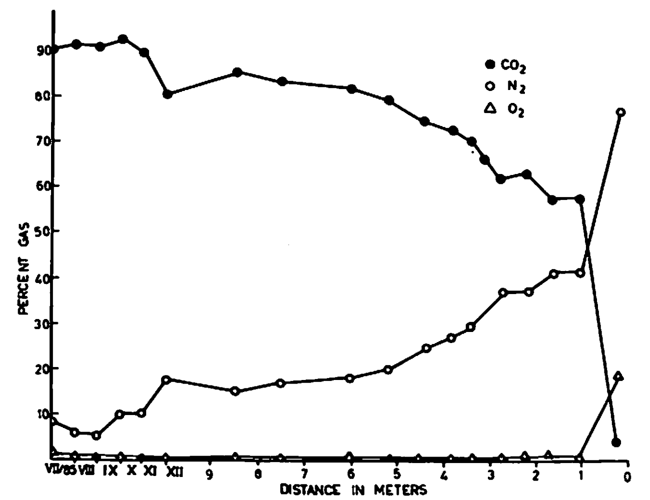

Fig. 1b. Changes in gas composition in bunker 1 - backward.

Table I: Number of days from start of unloading until the face was approximately 5 m and at the bags, respectively

Silage No.	5 m	End	Computed mean unloading rate (mm/day)
1 forward	55	90	111
1 backward	125	165	121
2 forward	25	60	167
2 backward	80	120	167
3	35	60	167
4	*	30	333

* not measured

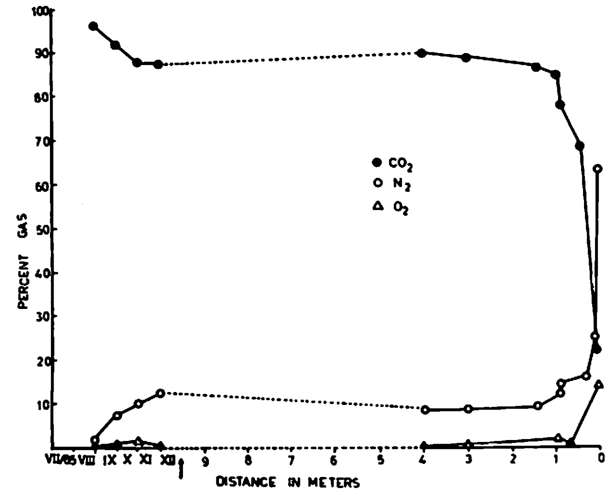

Fig. 2a. Changes in gas composition in bunker 2 - forward.

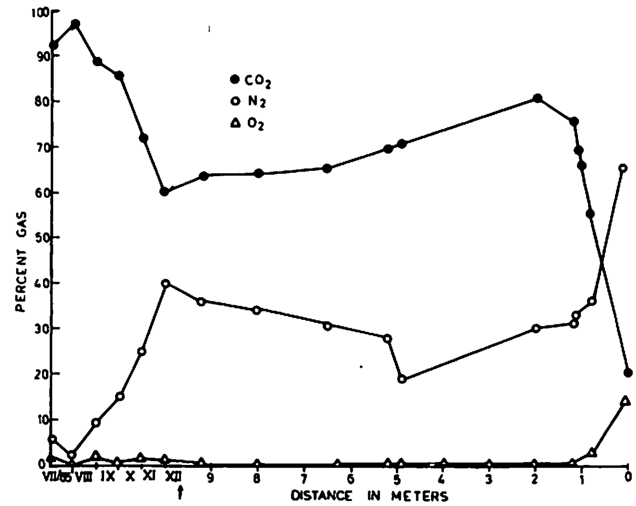

Fig. 3. Changes in gas composition in bunker 3.

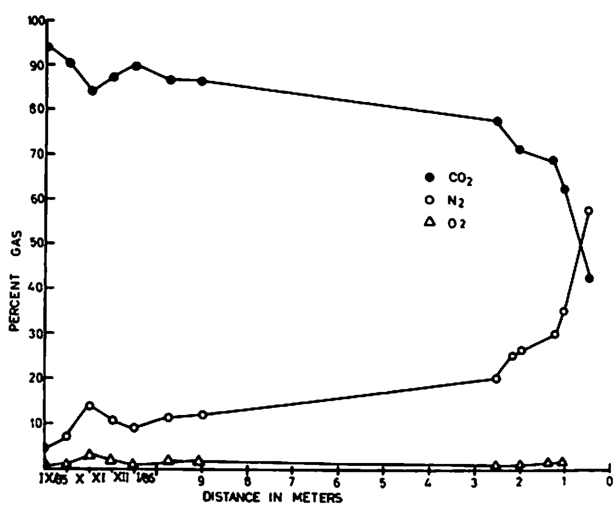

Fig. 2b. Changes in gas composition in bunker 2 - backward.

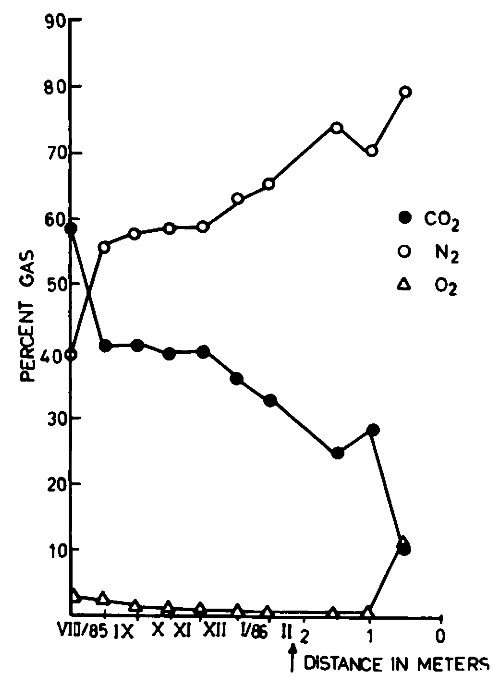

Fig. 4. Changes in gas composition in bunker 4.

declined sharply only in the last meter. In bunker 2, CO_2 levels in both sets remained high during storage and unloading, and declined only when the face was 1-2 m away. In bunker 3, CO_2 levels declined from 90 to 60% during storage, which might indicate air penetration. During feedout, there was a gradual increase in CO_2 levels, with a sharp decline in the last meter. In bunker 4, which was unusually narrow, so that unloading proceeded quickly, CO_2 levels were low from the beginning of storage and decreased even more during storage and feedout.

All silages were well preserved (Table II), with pH values of 4.0 or below and relatively low ash content. Ash contents indicate the extent of loss of organic matter (Dickerson et al. 1991). Microbiological counts of aerobic bacteria, yeasts and molds were also low, less than 10^3 colony-forming units per gram in most cases analyzed. Dry matter losses were not high, except for the forward area of bunker 2 (Table II). In this part of the silo, the top plastic sheeting was torn; wind blew in and rain penetrated into the silage.

From the results, it is not possible to relate changes in CO_2 and N_2 levels in the silages to DM losses. The stated level of compaction on farm scale ensilage in Israel is around 230 kg • m^{-3}, and it depends on many factors such as DM content, chopping length, and compaction (Israeli extension service tables). There was no information on level of compaction of the four silages, which could have explained differences in gas composition among them. All silages in this study were unloaded with a front-loading tractor, which disturbs the silage more than a silage cutter or scraper. The faces of silages 1, 3, and 4 were not smooth. This might have increased air ingress into the silages and subsequent losses (Pahlow and Honig 1993). The fast unloading rate of silage 4, in the narrow bunker (Table I), prevented the spoilage of

Table II: Chemical analysis of the corn silages (means ± SD)

Silage No.	%DM	Ash*	pH	WSC*	%DM losses
1 forward	34.8 ± 1.6	4.6 ± 0.2	3.6	3.4 ± 0.5	0.8 ± 2.2
1 backward	33.3 ± 0.9	4.3 ± 0.4	3.7	1.7 ± 0.1	3.5 ± 2.8
2 forward	25.7 ± 0.9	6.7 ± 0.4	4.0	3.1 ± 0.2	15.6 ± 5.6
2 backward	27.3 ± 0.5	7.4 ± 0.3	4.0	2.8 ± 0.5	4.7 ± 2.2
3	32.4 ± 0.7	4.5 ± 0.3	3.5	2.5 ± 0.1	5.8 ± 2.0
4	42.8 ± 2.0	5.6 ± 0.6	4.1	5.9 ± 1.4	4.9 ± 1.6

*% in DM. WSC = water-soluble carbohydrates

this silage in spite of the intensive air penetration (Fig. 4).

Honig (1991) showed that the penetration depth of air in a normally consolidated grass silage (at 50% DM) was around 1 m. This is similar to our results from bunkers 1-3. In Honig's study, the CO_2 levels at 2-3 m from the unloading front were 20-30%. These levels are lower than those found in the corn silages in our study at a similar distance from the unloading front. The DM density of the dry grass silage is lower than that of the corn silage. This might explain differences in air penetration and in gas composition between the grass and corn silages.

Ashbell and Weinberg (1992) recorded CO_2 levels in the top layer of corn and wheat silages. The top layer of silage is much more susceptible to air penetration than the inner parts and CO_2 levels in the top layers during storage were only 20-40% in the corn silage and 20-50% in the wheat silage. These levels are lower than those found in the present study in the center of the silages. For the same reasons, DM losses were higher (about 75%) in the previous study.

The processes that determine the extent of aerobic deterioration of silages are complex; they involve the intrinsic properties of the forage as well as silage management. Not all the factors involved in these processes have yet been elucidated. The gas composition profiles in silages presented in this paper could serve as a basis for designing future studies on aerobic deterioration of silages using model systems.

CONCLUSIONS

In well consolidated and sealed corn silage, CO_2 levels remain fairly high during storage. This indicates anaerobic conditions conductive to silage preservation. The silage is fully exposed to air when the unloading front is 1-2 m away. To avoid detrimental effects of exposure to air, the design of silos and unloading rates should allow fast feedout of silage slices before aerobic spoilage processes take place.

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