

Factors Affecting Carbon Dioxide Concentration in Interstitial Air of Soybean Stored in Hermetic Plastic Bags (Silo-bag)

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Abstract

In 2007 about 35 million tonnes of grains were stored in hermetic systems (silo-bags) in Argentina, and about 17 million tonnes of that were soybean. The soybean stored in these silo-bags is mostly used for processing in the local industry (oil and soy-meal), but also for seeds to be used during the next planting season. The goal of this research was to conduct a series of field experiments in order to identify the main factors affecting the CO₂ concentration as an indicator of biological activity and appropriate soybean storability conditions.

The experiments consisted of monitoring the gas composition of the interstitial air, grain moisture content (MC) and temperature of several silo-bags. Additionally, the overall condition of the silo-bags was checked (broken areas, improper sealing, bottom side perforations, etc). On average, biological activity, measured as CO₂ concentration, did not increase substantially when soybean MC increased from 11 to 15.2%. The CO₂ concentration for soybean with 14% MC or lower was below 2%. The average CO₂ concentrations for silo-bags with soybean at 14 to 15.2% MC remained below 2%, however, in some silo-bags the CO₂ concentration increased to 5% at the most. The average temperature of the soybean stored in silo-bags followed the pattern of the average ambient air temperature through the seasons. There was a small increase in the average CO₂ concentration as a function of the grain temperature increase (1.5% points of CO₂ for about 10°C of temperature increase). When individual silo-bags were analyzed, the CO₂ concentration measured during the warm storage season was up to 3 percentage points higher than when measured during the cold storage season.

Keyword: Grain quality, Biological activity, Modified atmospheres

Introduction

During the last 10 years in Argentina soybean production increased 31 million tonnes. As a result, the 2008 soybean harvest was estimated to be 47 million tonnes, representing almost half of the total grain production of the country^[1]. On the other hand, the permanent storage capacity did not increase at the same pace as production, so a substantial portion of the harvest, estimated almost 35 million tonnes, was stored in a temporary hermetic storage system, called silo-bags. About half of the grain stored in silo-bags was soybean (17 million tonnes).

Each silo-bag can hold approximately 180 tonnes of soybean and with the available handling equipment is quite simple to load and unload. These plastic bags are 60 m long, 2.74 m diameter and the plastic cover is made of three layers (white outside and black inside) with 235 micrometers of thickness. The silo-bags are waterproof and have a certain degree of

gas-tightness (oxygen (O₂) and carbon dioxide (CO₂)). As a result, respiration of the biotic components of the grain mass (fungi, insects and grain) increases CO₂ and reduces O₂ concentrations. When the biological activity is intense, the degree of modification of the typical atmospheric gas composition (21% O₂ and 0.003% CO₂) is greater, which would limit grain respiration and mold^[2] and insect development^{[3][4]}. It was also observed that high CO₂ concentration reduced the ability of *Aspergillus flavus* to produce aflatoxin (5).

Bartosik et al.^[6] summarized previous experiences of storing grain in silo-bags, where it was demonstrated that the grain temperature in the hermetically sealed plastic bags followed the pattern of the ambient temperature throughout the year, implying that temperature of the grain mass does not reveal biological activity in the grain mass. The average moisture content (MC) did not significantly change during any storage experiment for both dry and wet grains. In general, no MC stratification was observed in soybean silo-bags. However, a study of MC change in individual kernels stored in silo-bags showed a slight but significant increase in soybean MC at the top layer (from 11.7 to 12.6 in 60 days)^[7]. In general, when grain was stored at the market MC, no significant decrease in the quality parameters was observed during 150 days of storage, and when grain was stored above the market MC, the decrease in some of the quality parameter was observed. However, soybean stored at 12.5% MC resulted in a reduction in the germination test, although other works showed different results^[8]. The increase in the CO₂ concentration was higher at the end of the storage time and also was higher in those bags with wetter grain (7.5% of CO₂ for 12.5% MC, and 16.2% of CO₂ for 15.6% MC after 160 days of storage). Based on this observations the authors hypothesized that measurement of gas composition in the interstitial air could be used as an indication of the biological activity of the grain mass in the hermetic storage system, and serve a tool for monitoring grain storability. However, a better understanding of typical CO₂ concentrations for soybean silo-bags is required to use this technology for monitoring grain storability.

Figure 1 shows a diagram of the main factors affecting respiration of the grain and microorganisms in the hermetic storage system and the relationship among them. Based on this model, the CO₂ and O₂ concentration in the silo-bag depends on the balance between respiration (consumption of O₂ and generation of CO₂), the entrance of external O₂ to the system, and the loss of CO₂ to the ambient air. The movement of gases in and out of the silo-bags depends on the gas partial pressure differential and the permeability of the system (through openings in the plastic cover, or through the natural permeability of the plastic material to the gases). Grain type and condition, MC, temperature, storage time, and O₂ and CO₂ concentrations affect the respiration rate. The temperature of the grain depends on the initial grain temperature (this effect is less important as the storage period increases), the effect of the sun radiation, the heat release from the respiration process, and the transfer of heat with the air and soil (grain temperature increases during spring and summer and decreases during fall and winter). The grain MC depends on the initial grain MC, the entrance of moisture from the outside (through openings after a rain event into broken or poorly sealed silo-bags), and the moisture released from the respiration process. Additionally, due to the day and night temperature differential, some moisture condensation can occur in the top grain layers resulting in a localized spot of wetter grain.

Thus, the goal of this research was to study the effect of grain MC and temperature on CO₂ concentration in silo-bags holding soybean.

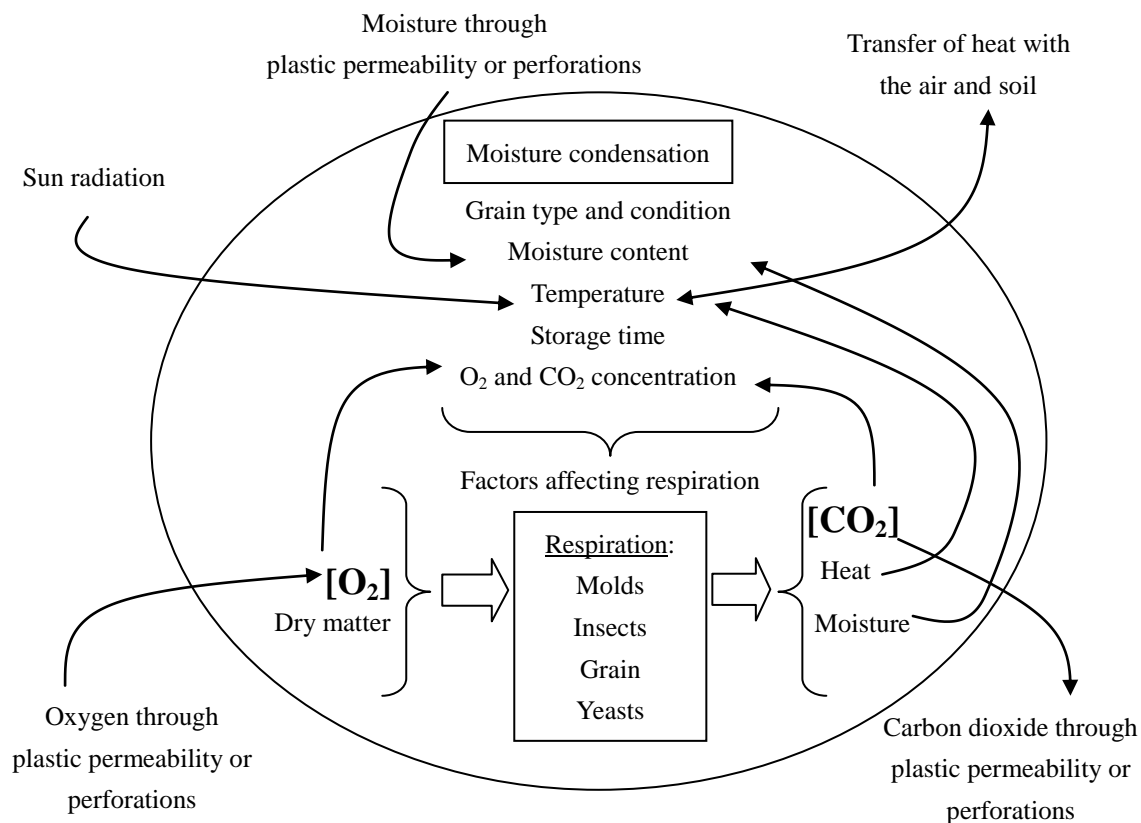


Fig. 1. Diagram of the main factors affecting respiration of grain and microorganisms in the silo-bag, the relationships among them, and the final O₂ and CO₂ concentrations.

Materials and Method

The tests were carried out at grain elevators and on farms in the South East of Buenos Aires province, Argentina during 10 months, from April 2007 to January 2008. Most of the soybean silo-bags were filled in April-May and stored until October or November. However, a small proportion of them were stored for one year period or longer. The silo-bags were sampled every 15 days during the entire storage period.

For each silo-bag two sampling locations were established. The procedure consisted of measuring first the gas concentration (O₂ and CO₂) with a portable gas analyzer (PBI Dan Sensor, CheckPoint, Denmark), perforating the plastic cover with a needle. The gas composition was analyzed for three levels in each sampling location, close to the top of the bag, at the middle and close to the bottom.

After the gas composition was analyzed, a wooden stick with three temperature sensors was inserted in the grain mass (diagonally, from the top and side to the bottom and center of the silo-bag) to measure grain temperature at approximately 0.1, 0.7 and 1.4 m from the surface.

In each sampling location grain was collected from three different levels (surface = 0.10 m depth, middle = 0.75 m depth, and interior = 1.6 m depth. Total height of the bag = 1.7 m) using a standard torpedo probe. Material from each one of the three sampling locations was segregated by level (top, middle, and bottom). The grain samples were stored in a hermetic plastic bag and brought to the Grain Postharvest Laboratory of the Balcarce Experimental

Station of the National Institute of Agricultural Technologies (INTA). After probing the silo-bags, the openings were sealed with a special tape in order to restore the air-tightness. At the laboratory, grain samples were analyzed for MC (GAC 2100, Dickey-John).

Additional information of the silo-bag was collected, such as filling and sealing quality, history of openings, perforations due to wild animals or bad sealing after sampling, improper preparation of the soil where the silo-bag was placed (when silo-bags were assembled on top of crop residues it resulted in perforations of the bottom), silo-bags assembled in low lands with risk of flooding, and any other relevant information.

Results and discussion

Figure 2 shows the relationship between grain MC and CO₂ concentration. The data corresponds to silo-bags without visible structural problems, although data from some silo-bags with perforations in the bottom side that were not noticed during sampling might be included.

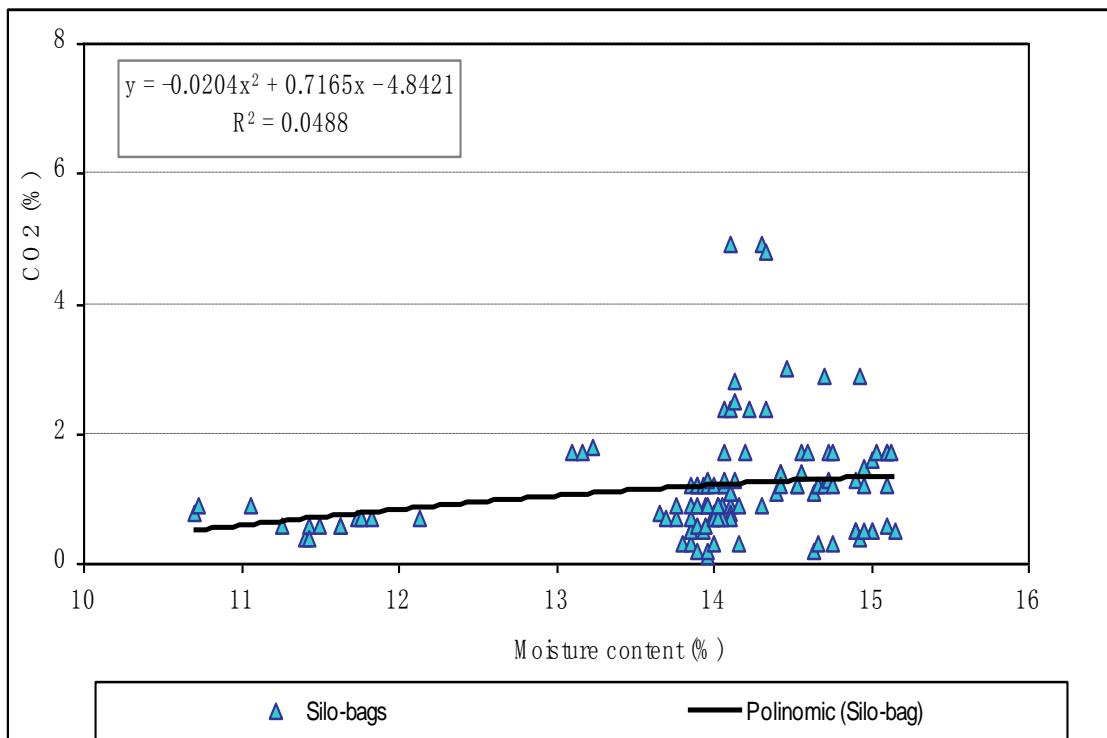


Fig. 2. CO₂ concentration in silo-bags as function of soybean moisture content.

The CO₂ concentration tended to increase very slowly with the increase in grain MC, which most likely was a consequence of the higher biological activity of wet grain (although the R² was very low, less than 5%). When the soybean MC was lower than 14% the average CO₂ concentration was below 2% (presumably due to grain respiration). When the soybean MC increased to the point in which molds became active (above 14%) the CO₂ concentration of some silo-bags increased up to 5%. Compared to data from wheat silo-bags^[9], the relationship between grain MC and CO₂ concentration was less clear for soybean. Additionally, soybean had less biological activity at the same MC, because for 13% MC the CO₂ concentration was below 2%, while for 13% MC wheat the average CO₂ concentration was about 5%. When the

soybean MC increased to 14-15%, the maximum CO₂ concentration was about 5% (1.5% average), while in wheat silo-bags for the same MC range the maximum CO₂ concentration was 20% and the average between 7.5 and 12%.

Figure 3 shows the relationship between the average ambient air temperature (data collected from the weather station of Balcarce Experimental Station) and the average soybean temperature in the silo-bags throughout the year.

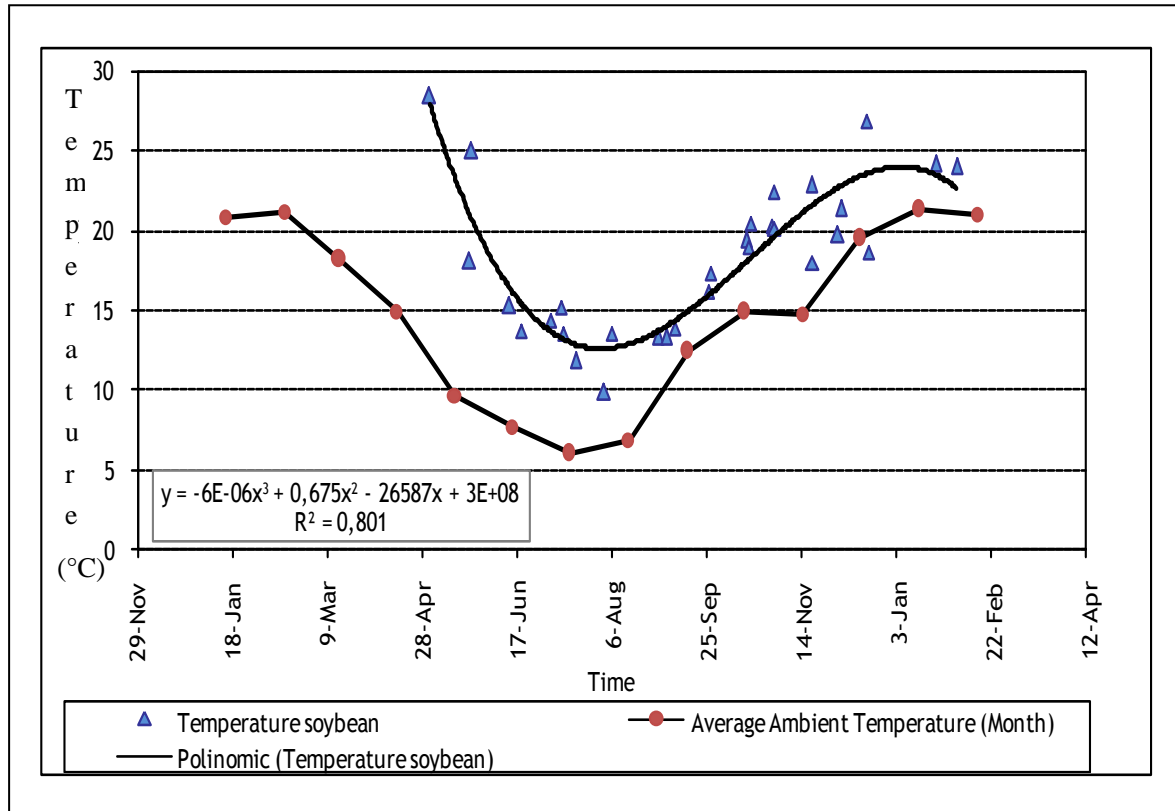


Fig. 3. Average ambient air temperature and average temperature of soybean stored in silo-bags.

This data is in agreement with the data shown by Bartosik et al.^[6], where it was demonstrated that the average grain temperature follows the pattern of the average ambient air temperature. From this figure, it can be appreciated that in the early fall (April) the soybean temperature was above 25°C (most likely soybean was harvested during a warm day). It was hypothesized that grain stored in the silo-bag can easily exchange heat with the air and soil through the large surface area. The surface/volume ratio of a 180 tonnes silo-bag is approximately 1.42, while for a standard metal silo of the same capacity (7 m diameter and 9 m height) the ratio is 44% lower (0.79). As a result, the soybean temperature decreased to about 10-15°C during the winter (June-August) as the average ambient air temperature decreased to 7°C or lower during the same season. When the average ambient air temperature increased to 15°C during the early spring and 20°C later (September-November), the grain temperature increased to 15°C and to 25°C, respectively.

Figure 4 shows the CO₂ concentration for silo-bags sampled during the winter and spring. Storage temperature affects biological activity, reducing the respiration rate of grain and

microorganisms. During the winter time, when the grain temperature was below 15°C, the CO₂ concentration was below 2% for soybean with 13% MC or less, below 3% for soybean between 13 and 14% MC, and below 5% with soybean between 14 and 15.3% MC. When the grain temperature increased during the spring (up to 25°C, Figure 3), the CO₂ concentration increased about 2.5-3% points for all MC values (up to 4.5% CO₂ for soybean below 13.5% MC, and up to 8% CO₂ for soybean between 13.5 and 15.2% MC). However, the average CO₂ concentration did not increase substantially with the increase in temperature, as shown in the trend lines.

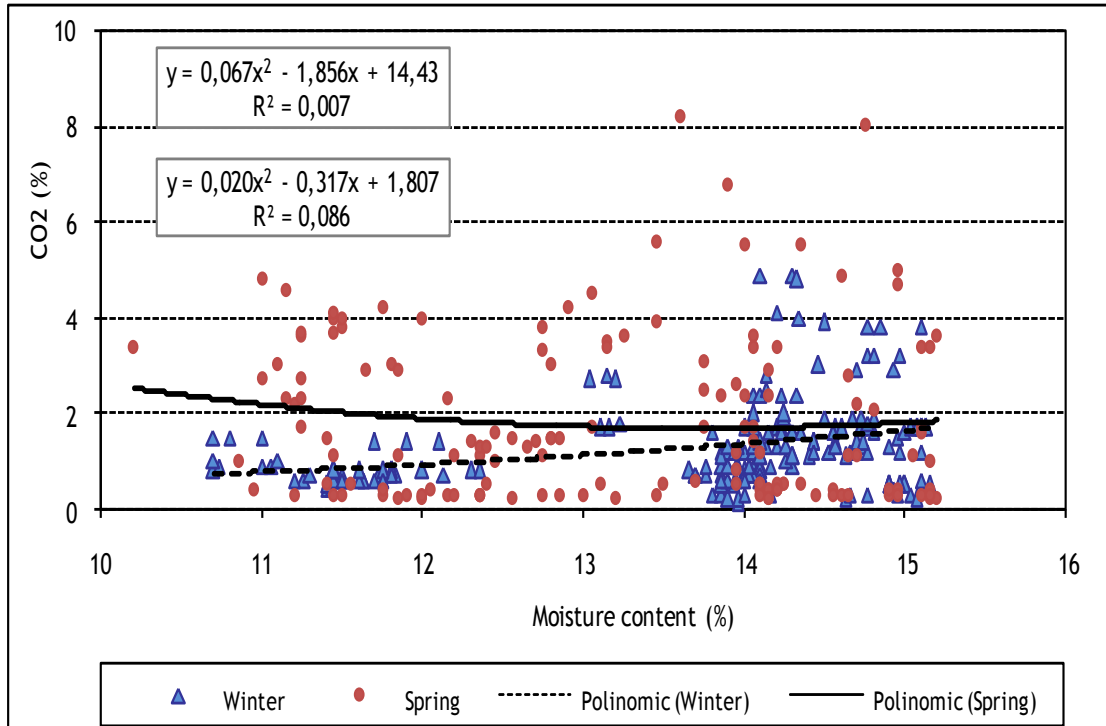


Fig. 4. CO₂ concentration at different grain moisture content for silo-bags sampled during the winter and spring.

Conclusions

On average, the increase of biological activity, measured as CO₂ concentration, did not increase substantially when soybean MC increased from 11 to 15.2%. The CO₂ concentration for soybean with 14% MC or lower was below 2%. The average CO₂ concentrations for silo-bags with soybean at 14 to 15.2% MC remained below 2%; however, in some silo-bags the CO₂ concentration increased to 5%.

The average temperature of the soybean stored in silo-bags followed the pattern of the average ambient air temperature through the seasons. There was a small increase in the average CO₂ concentration as a function of the grain temperature increase (1.5% points of CO₂ for about 10°C of temperature increase). When individual silo-bags were analyzed, the CO₂ concentration measured during the warm storage season was up to 3 percentage points higher than when measured during the cold storage season.

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