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## Effects of free air carbon dioxide enrichment and drought stress on the rumen in sacco degradability of corn silage harvested at various times

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### Abstract

The present study investigated the effects of increased atmospheric CO<sub>2</sub> concentration, drought stress and harvest date on the rumen in sacco dry matter degradability of corn silage. A free air carbon dioxide enrichment facility (FACE) was operated in a field to generate a CO<sub>2</sub> concentration of 550 ppm in three treatment plots. Three plots served as control. All plots were divided into two semicircles to produce drought stress by the exclusion of precipitation in one half each. Corn plants were harvested at three dates (26 August, 12 September, 29 September 2008), chopped, ensiled, dried and ground. The in sacco degradability after 2, 4, 8, 16, 24, 48 and 96 h was evaluated using six non-lactating rumen cannulated Holstein cows. The potential dry matter degradability, the sum of water soluble and degradable insoluble fraction, was not affected by CO<sub>2</sub> elevation. A low CO<sub>2</sub> effect below 1 % unit was found on the effective degradability, which is calculated in consideration of an assumed rate of passage from the rumen. Drought did not alter the potential degradability, but the kinetics of dry matter degradation and decreased the effective degradability by 2 % units. Harvest date affected all degradation parameters. Later harvest was related to an increased potential but reduced effective degradability. The potential degradability had close inverse relationships to neutral detergent fibre concentration ( $r = -0.74$ ,  $P < 0.01$ ) but was positively correlated to starch ( $r = 0.80$ ,  $P < 0.01$ ) and DM ( $r = 0.80$ ,  $P < 0.01$ ). The correlations between effective degradability and crude nutrients were generally not significant. Harvest date will remain an important factor influencing the feed value of corn silage, but the effects of elevated CO<sub>2</sub> concentration and drought stress did not indicate considerable impacts.

*Keywords:* CO<sub>2</sub> concentration, drought stress, in sacco degradability, corn silage, harvest date

### Zusammenfassung

#### Einfluss von erhöhter CO<sub>2</sub>-Konzentration, Trockenstress und Erntezeitpunkt auf die in sacco Abbaubarkeit von Maissilage

Die Effekte von erhöhter atmosphärischer CO<sub>2</sub>-Konzentration, Trockenstress und Erntezeitpunkt auf die in sacco Abbaubarkeit der Trockensubstanz von Maissilage wurden untersucht. Unter Verwendung von Freiluft CO<sub>2</sub>-Expositionstechnik wurde in einem Maisfeld an drei Stellen eine erhöhte CO<sub>2</sub>-Konzentration von 550 ppm generiert. Drei weitere Flächen dienten als Kontrolle. In der Hälfte jeder Stelle erfolgte die Erzeugung von Trockenstress durch Niederschlagsausschluss. Maispflanzen wurden an drei Zeitpunkten geerntet, siliert und vermahlen. Zur Ermittlung der in sacco Abbaubarkeit der Trockensubstanz nach 2, 4, 8, 16, 24, 48 und 96 Stunden wurden sechs am Pansen fistulierte Kühe verwendet. Die potentielle Abbaubarkeit, die Summe aus wasserlöslicher und unlöslicher Fraktion, wurde nicht durch die CO<sub>2</sub>-Konzentration beeinflusst. Allerdings konnte ein geringer CO<sub>2</sub> Effekt von unter 1 %-Punkt auf die effektive Abbaubarkeit, welche unter Berücksichtigung einer angenommenen Passage-rate aus dem Pansen errechnet wird, festgestellt werden. Trockenstress veränderte die potentielle Abbaubarkeit nicht, beeinflusste jedoch die Kinetik des Abbaues und reduzierte die effektive Abbaubarkeit um 2 %-Punkte. Der Erntezeitpunkt beeinflusste alle untersuchten Abbauparameter. Spätere Ernte induzierte eine erhöhte potentielle, aber verminderte effektive Abbaubarkeit. Die potentielle Abbaubarkeit war negativ mit den Gehalten an neutraler Detergenzienfaser ( $r = -0,74$ ,  $P < 0,01$ ) sowie negativ mit den Gehalten an Stärke ( $r = 0,80$ ,  $P < 0,01$ ) und Trockensubstanz ( $r = 0,80$ ,  $P < 0,01$ ) korreliert. Der Erntezeitpunkt wird ein bestimmender Faktor für den Futterwert von Maissilage bleiben. Die Effekte von steigender atmosphärischer CO<sub>2</sub>-Konzentration und Trockenstress lassen nicht auf nennenswerte Veränderungen schließen.

*Schlüsselwörter:* CO<sub>2</sub> Konzentration, Trockenstress, in sacco Abbaubarkeit, Maissilage, Erntezeitpunkt

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## 1 Introduction

Changing climatic conditions will likely affect both crop and livestock production with considerable regional differences. Since the beginning of human industrialisation, the atmospheric CO<sub>2</sub> concentration has risen from about 280 ppm to a current value of approximately 390 ppm and may exceed 700 ppm by the middle and 1000 ppm by the end of the century, depending on the prospective greenhouse emission scenario (IPCC, 2007). According to the same survey, many regions in different parts of the world may be affected by a higher incidence of drought.

Various effects of elevated atmospheric CO<sub>2</sub> concentrations on photosynthesis, yield and chemical composition of C<sub>3</sub> plants such as decreased forage and grain protein contents were reported (Schenk et al., 1997; Wu et al., 2004; Weigel and Manderscheid, 2005; Yang et al., 2007; Manderscheid et al., 2009). In contrast, C<sub>4</sub> plants do not respond to increasing CO<sub>2</sub> concentrations with an increase of photosynthesis and biomass production due to their CO<sub>2</sub> concentration mechanism in the leaves which serves to saturate photosynthesis in ambient air (Ghannoum, 2009). However, in both C<sub>3</sub> and C<sub>4</sub> plants decreased stomatal water loss can be observed under elevated CO<sub>2</sub> concentrations. For example, decreased stomatal plant water loss of corn (*Zea mays L.*) was observed using free air carbon dioxide enrichment (FACE) technology (Leakey et al., 2006). Consequently, positive CO<sub>2</sub> effects on C<sub>4</sub> crops like corn may only be observed under water shortage potentially reducing the negative effects of drought. While the physiological mechanisms of CO<sub>2</sub> x drought interactions are basically known there is little evidence from field scale studies under true agronomic growth conditions testing the consequences of changes of these important climate change factors on crop growth and food quality (DaMatta et al., 2010).

More information about possible impacts of rising CO<sub>2</sub> and its interactions with water supply on corn are necessary as besides the immense importance for human food supply whole plant corn silage is used prevalently as a main component of dairy and beef cattle diets to meet the requirements of high-yielding animals. Both chemical composition and feed value of corn silage strongly depend on plant maturity. Later harvest date was reported to reduce the in sacco degradability of cob-free corn plants (Flachowsky et al., 1993; Akbar et al., 2002). Nevertheless, within the process of starch deposition in the cob later harvest results in a decreased cell wall but increased starch content in whole corn plants indicating an improved ruminal degradability, though the proportion of bypass-starch that is not degradable in the rumen may rise with advanced maturity (Johnson et al., 2003; Filya, I., 2004).

The aim of the present study was to investigate effects of elevated atmospheric CO<sub>2</sub> concentration and drought stress on the ruminal in sacco degradability of whole plant corn silage harvested at different harvest dates.

## 2 Materials and methods

### 2.1 FACE experiment and sampling

In 2008, the corn variety "Romario" (S 240, K 240) was planted on an experimental field of the Institute of Biodiversity, Johann Heinrich von Thünen-Institut, Federal Research Institute for Rural Areas, Forestry and Fisheries, Braunschweig, Germany (52°18'N, 10°26'E, 79 m a.s.l.), according to local farm practices. A FACE (Free air carbon dioxide enrichment) system was operated as described by Lewin et al. (1992). Treatments included three rings with blowers and CO<sub>2</sub> enrichment to meet a target CO<sub>2</sub> concentration of 550 ppm during daylight hours (FACE) and three control rings operated with blowers and ambient air of approximately 380 ppm (Control), respectively. The rings had an outer diameter of 20 m and were divided into 2 semicircles. A facility for the exclusion of precipitation in a rain-laden summer was designed to generate drought stress in one semicircle each (drought stress). Water was provided continuously via drip-irrigation in the other semicircles to exceed 50 % field capacity (well watered).

Five whole plants per semicircle were harvested manually within an inner diameter of 16 m at three sampling dates each (26 August (1), 12 September (2) and 29 September (3)). The corn plants were chopped and stored at -18 °C. After defrosting, the samples from all semicircles per treatment and harvest were pooled. Ensiling was performed for 28 consecutive days in airtight glass laboratory jars containing a volume of 2.5 l each. The jars were kept at a constant temperature of 25 °C. Afterwards, the samples were freeze dried for 48 h (Epsilon I/15, Martin Christ Gefriertrocknungsanlagen GmbH, Osterode, Germany) and ground to pass through a 3 mm sieve for further analyses (DR 100/15-40, Retsch GmbH, Haan, Germany).

### 2.2 In sacco degradability

The in sacco experiment was conducted at the experimental station of the Institute of Animal Nutrition, Friedrich-Loeffler-Institute (FLI), Federal Research Institute for Animal Health, Braunschweig, Germany. Six non-lactating German Holstein cows with a mean initial bodyweight of 663 ± 69 kg equipped with large rubber cannulas in the dorsal rumen sac were used. The animals were kept in a tethered barn with individual troughs and free access to water. The cows were fed on 8.2 kg dry matter (DM) silage mixture, consisting of 60 % corn and 40 % grass silage, 2 kg concentrate mixture and 100 g mineral and vitamin premix per day. The diet was presented twice daily in equal portions at 5:30 h and 15:30 h. 4 ± 0.1 g of ground corn silage samples were weighed in nylon bags (100 x 200 mm, pore size 50 ± 15 µm, Ankom Technology, New York,

USA). Two samples of every treatment were incubated in the rumen of each cow 30 minutes before morning feeding for 2, 4, 8, 16, 24, 48 and 96 hours. Immediately after removal from the rumen the bags were transferred into iced water to inhibit microbial activity followed by a cleaning in cold water using a washing machine. Subsequently the samples were oven-dried at 60 °C for 24 hours and weighed. For the determination of the water soluble fraction four bags of each treatment were subjected to the same procedure except the incubation in the rumen.

### 2.3 Chemical analyses

Water soluble carbohydrates (WSC) in fresh whole corn plants were determined via colorimetry using anthrone as described by Laws and Oldenburg (1993). Fermentation acids and ethanol in corn silages were measured following Canale et al. (1984) and Siegfried et al. (1984). The composition of the corn silages (DM, crude ash, crude protein, ether extract, starch, neutral detergent fibre (NDF) and acid detergent fibre (ADF)) was determined according to the methods of the Association of German Agricultural Analysis and Research Centres (VDLUFA, 1976). NDF and ADF were expressed without residual ash.

### 2.4 Calculations

The content of DM in the examined silages was corrected for potential substance losses during drying following the equation for corn silages given by Weissbach and Kuhla (1995).

The ruminal in sacco degradability was determined according to Ørskov and McDonald (1979). Dry matter degradability data were fitted to the non-linear degradation equation  $p = a + b(1 - e^{-ct})$ , where p is the DM degradation (%) at time t, a represents the intercept of the degradation curve at time zero or the water soluble fraction including small but insoluble particles, b is the insoluble, but degradable fraction, c is the rate of degradation of b (% h<sup>-1</sup>) and a + b represents the potential degradability.

The effective degradability was calculated by the equation  $P = a + bc / (c + k)$  (McDonald, 1981), where k is the assumed fractional rate of passage of 0.05 h<sup>-1</sup> from the rumen following Tothi et al. (2003).

### 2.5 Statistical Analysis

Statistical analyses were performed using the software package SAS version 9.1. DM degradation parameters were analyzed by the GLM procedure. CO<sub>2</sub> concentration (CO<sub>2</sub>), irrigation (I) and harvest date (H) were used as the class variables in the model. Pearson correlation coefficients were calculated using the procedure "CORR".

The content of water soluble carbohydrates in fresh corn plants and the chemical composition of the generated corn silages could not be subjected to statistical analysis since the samples from all plots per treatment were pooled before ensiling. Differences were considered to be significant at P < 0.05. Trends were declared at P < 0.1.

## 3 Results

### 3.1 Chemical composition

The pH values and the concentration of fermentation acids and ethanol of the investigated corn silages are given in Table 1. pH was found to be generally below 4.0 and the contents of butyric acid were below 0.05 % of DM in all samples. Water soluble carbohydrates in fresh plants and the crude nutrient contents of the experimental corn silages are presented in Table 2. The nominal effects of both atmospheric CO<sub>2</sub> concentration and irrigation on the chemical composition were low or not existent. Later harvest was accompanied by a considerable decline of WSC in fresh samples. Furthermore, progressing maturity resulted in nominally increased silage DM and starch but decreased fibre content. However the CO<sub>2</sub> control sample grown under drought stress and harvested at 29 September showed a reduced starch concentration and an increase of WSC compared to all other treatments at the third harvest. Moreover, the increase of WSC was already visible at the first harvest date.

Table 1: Fermentation acids, ethanol and pH in corn silages (% dry matter).

CO <sub>2</sub>	Treatment <sup>a</sup>		Parameter					
	I	H	Acetic acid	Propionic acid	Butyric acid	Lactic acid	Ethanol	pH
FACE	WW	1	0.3	0.02	0.00	7.6	0.5	3.6
		2	0.5	0.03	0.03	6.5	0.3	3.6
		3	0.4	0.14	0.02	5.9	0.4	3.7
	DS	1	0.3	0.05	0.00	7.7	1.0	3.6
		2	0.2	0.06	0.00	6.4	0.4	3.7
		3	0.5	0.05	0.00	5.6	0.3	3.8
Control	WW	1	0.4	0.02	0.00	7.9	0.3	3.5
		2	0.3	0.09	0.01	6.1	0.8	3.7
		3	0.3	0.09	0.01	5.6	0.4	3.7
	DS	1	0.3	0.04	0.00	7.9	1.5	3.6
		2	0.2	0.08	0.00	5.9	0.3	3.7
		3	0.6	0.00	0.00	6.3	0.4	3.8

<sup>a</sup> Treatments were CO<sub>2</sub> concentration (CO<sub>2</sub>, FACE vs. Control), irrigation (I, Well Watered (WW) vs. Drought Stress (DS)) and harvest date (H, 26 August (1), 12 September (2) and 29 September (3)).

Table 2:

Water soluble carbohydrates in fresh corn plants (% DM) as well as DM (% fresh matter) and crude nutrient content of corn silages (% DM).

CO <sub>2</sub>	Treatment <sup>a</sup>		Parameter <sup>b</sup>							
	I	H	WSC	DM	Ash	CP	EE	NDFom	ADFom	Starch
FACE	WW	1	15.2	27.3	4.5	5.8	1.8	51.3	26.7	21.7
		2	9.4	31.8	3.9	6.0	2.7	44.4	24.6	30.0
		3	8.1	35.5	4.2	5.1	2.5	42.9	22.8	32.6
	DS	1	16.8	28.1	4.3	5.8	2.0	51.3	26.2	17.4
		2	10.9	33.5	3.8	5.6	2.5	47.2	24.0	26.6
		3	6.5	41.2	3.7	5.1	2.5	45.3	23.3	31.9
Control	WW	1	15.7	26.3	4.1	5.9	1.9	49.4	25.8	18.6
		2	9.2	32.5	3.8	5.1	2.4	48.4	25.0	28.3
		3	8.5	37.1	3.9	5.0	2.4	40.9	20.9	35.7
	DS	1	21.1	28.9	4.1	6.3	1.8	52.1	26.1	15.2
		2	11.2	34.8	3.6	5.5	2.4	48.6	24.1	27.3
		3	9.8	39.7	4.1	6.3	2.1	47.3	24.3	26.7

<sup>a</sup> Treatments were CO<sub>2</sub> concentration (CO<sub>2</sub>, FACE vs. Control), irrigation (I, Well Watered (WW) vs. Drought Stress (DS)) and harvest date (H, 26 August (1), 12 September (2) and 29 September (3)).

<sup>b</sup> WSC, water soluble carbohydrates; DM, dry matter; Ash, crude ash; CP, crude protein; EE, ether extract; NDFom, neutral detergent fibre expressed without residual ash; ADFom, acid detergent fibre expressed without residual ash.

Table 3:

Effects of atmospheric CO<sub>2</sub> concentration, irrigation and harvest date on degradation parameters (%) of corn silage DM (Means ± SD, n=6).

CO <sub>2</sub>	Treatment <sup>a</sup>		Parameter <sup>b</sup>				
	I	H	a	b	c	a + b	P
FACE	WW	1	35.9 ± 1.1	32.1 ± 1.0	0.035 ± 0.003	68.0 ± 1.0	49.1 ± 0.6
		2	35.0 ± 0.8	37.3 ± 2.1	0.032 ± 0.007	72.3 ± 2.2	49.5 ± 1.3
		3	34.2 ± 1.0	39.2 ± 1.7	0.032 ± 0.006	73.4 ± 1.2	49.4 ± 1.5
	DS	1	34.0 ± 0.4	33.3 ± 1.2	0.037 ± 0.006	67.3 ± 1.2	48.1 ± 1.1
		2	33.0 ± 1.4	39.4 ± 1.8	0.030 ± 0.005	72.3 ± 2.0	47.6 ± 1.0
		3	29.7 ± 0.7	46.6 ± 0.7	0.028 ± 0.002	76.3 ± 1.0	46.2 ± 1.0
Control	WW	1	36.4 ± 0.5	32.9 ± 1.3	0.033 ± 0.006	69.6 ± 1.3	49.7 ± 1.2
		2	32.4 ± 0.8	40.1 ± 2.2	0.030 ± 0.004	72.5 ± 2.0	47.5 ± 1.4
		3	33.9 ± 0.9	40.9 ± 1.3	0.030 ± 0.005	74.8 ± 1.9	49.0 ± 1.1
	DS	1	35.6 ± 0.8	32.7 ± 1.8	0.033 ± 0.007	68.3 ± 1.9	48.4 ± 1.3
		2	32.7 ± 0.7	39.7 ± 0.8	0.032 ± 0.005	72.4 ± 0.8	48.1 ± 1.3
		3	27.3 ± 1.1	45.7 ± 1.6	0.027 ± 0.004	73.0 ± 1.4	43.3 ± 1.1
P-value							
CO <sub>2</sub>			0.020	0.072	0.251	0.647	0.027
I			<0.001	<0.001	0.461	0.610	<0.001
H			<0.001	<0.001	0.002	<0.001	<0.001
CO <sub>2</sub> × I			0.388	0.004	0.592	0.017	0.926
CO <sub>2</sub> × H			<0.001	0.226	0.592	0.050	0.011
I × H			<0.001	<0.001	0.306	0.223	<0.001
CO <sub>2</sub> × I × H			<0.001	0.765	0.560	0.027	0.003

<sup>a</sup> Treatments were CO<sub>2</sub> concentration (CO<sub>2</sub>, FACE vs. Control), irrigation (I, Well Watered (WW) vs. Drought Stress (DS)) and harvest date (H, 26 August (1), 12 September (2) and 29 September (3)).

<sup>b</sup> a = water soluble fraction, b = insoluble, but degradable fraction, c = rate of degradation of b (% h<sup>-1</sup>), a+b = potential degradability, P = effective degradability.

### 3.2 In sacco degradability

The potential ruminal DM degradability (a + b) of the investigated silages was found to be generally below 80 % (Table 3). Assuming a rate of passage of 0.05 h<sup>-1</sup> from the rumen, the estimated effective DM degradability (P) did not exceed 50 %. The lowest values of both water soluble fraction (a) and effective degradability were observed for the CO<sub>2</sub> control sample grown under drought stress and harvested at 29 September which was characterized by a low starch but high fibre content, compared to the other treatments.

Though the atmospheric CO<sub>2</sub> concentration had significant effects on water soluble fraction and effective degradability, the nominal impacts on both parameters were below 1 % unit and the other degradation parameters were not influenced by CO<sub>2</sub> enrichment. Drought stress decreased the water soluble fraction and the effective degradability of the incubated samples by 2.5 and 2 % units, respectively. However the insoluble, but degradable fraction (b) was increased by 2.5 % units resulting in a lack of impacts of drought stress on the potential degradability of silage DM. Harvest date had a significant effect on all calculated degradation parameters and altered both DM degradation kinetics and degradability. Later harvest resulted in a decreased water soluble fraction and effective degradability as well as a slower rate of DM degradation. However, the rising insoluble, but degradable fraction overcompensated these effects and the potential degradability increased with later harvest. The pooled potential degradabilities were 71.6 ± 3.4 % for FACE and 71.8 ± 2.7 % for CO<sub>2</sub> Control treatment, 71.8 ± 2.9 % for well watered and 71.6 ± 3.3 % for drought stress treatment as well as 68.3 ± 1.5 %, 72.4 ± 1.7 % and 74.4 ± 1.9 % for harvest 1, 2 and 3, respectively.

Though various interactions were found to influence the kinetics of DM degradation significantly, the nominal differences were mostly low or undirected. Interestingly, CO<sub>2</sub> elevation resulted in a slightly higher potential degradability during drought stress (1 % unit) but lower a + b (0.7 % unit) during sufficient water supply (CO<sub>2</sub> x I. P = 0.017). Furthermore, the CO<sub>2</sub> x I x H interaction was found to be significant for the potential degradability (P = 0.027). For harvest 3, the CO<sub>2</sub> control samples showed a reduced a + b when grown under drought stress (3 % units).

WSC in fresh samples and the cell wall contents of the produced silages were found to have close inverse relationships to the insoluble, but degradable fraction and the potential degradability, respectively, however ADFom was closer negatively correlated to the fraction b than NDFom (Table 4). Furthermore, positive relationships of WSC and ADFom to both water soluble fraction and rate of DM degradation were observed. Both silage DM and starch content were positively correlated to the insoluble,

but degradable fraction and the potential degradability, respectively, but had negative relationships to the other degradation parameters. Except for DM, the correlations between the examined nutrients and the effective degradability were generally not significant.

Table 4:

Correlation coefficients between degradation parameters and water soluble carbohydrates in fresh corn plants (% DM), silage DM (% fresh matter) as well as silage crude nutrient contents (% DM).

Parameter <sup>a</sup>	Fraction <sup>b</sup>				
	WSC	DM	ADFom	NDFom	Starch
a	0.54**	-0.79**	0.43**	0.22	-0.39**
b	-0.79**	0.93**	-0.71**	-0.58**	0.71**
c	0.35**	-0.43**	0.35**	0.28**	-0.32**
a + b	-0.81**	0.80**	-0.77**	-0.74**	0.80**
P	0.23	-0.53**	0.17	-0.04	-0.08

<sup>a</sup> a = water soluble fraction, b = insoluble, but degradable fraction, c = rate of degradation of b (% h<sup>-1</sup>), a + b = potential degradability, P = effective degradability.

<sup>b</sup> WSC, water soluble carbohydrates; DM, dry matter; Ash, crude ash; NDFom, neutral detergent fibre expressed without residual ash; ADFom, acid detergent fibre expressed without residual ash.

\*: P < 0.05, \*\* P < 0.01.

## 4 Discussion

In a recent study, Porteaes et al. (2009) investigated the responses of the nutritive value of wheat (*Triticum aestivum* L.) straw and grain to an increased atmospheric CO<sub>2</sub> concentration of 550 ppm and reported the quality to be altered in a potentially adverse fashion. Though the composition of wheat straw was generally not affected by CO<sub>2</sub> enrichment, significant reductions of crude protein and NDF in grain DM were reported to be accompanied by increased starch concentrations. In C<sub>4</sub> plants, CO<sub>2</sub> is concentrated in the leaves (Ghannoum, 2009) and the effect of elevated atmospheric CO<sub>2</sub> will therefore likely be limited. Leakey et al. (2006) demonstrated in a FACE experiment that increased atmospheric CO<sub>2</sub> did not stimulate corn photosynthesis, yield, the activity of key photosynthetic enzymes or metabolic markers of carbon and nitrogen status in the absence of drought. In a recent FACE trial CO<sub>2</sub> enrichment did not increase corn growth and yield under sufficient water supply but under drought stress (Manderscheid et al., 2011). Accordingly, the effects of increased CO<sub>2</sub> on both water soluble fraction and effective ruminal degradability of the investigated corn silages did not indicate relevant alterations of the feed value in the present experiment as for both parameters the nominal differences between the CO<sub>2</sub> treatments were below 1 % unit.

Drought stress can decrease biomass and grain yield of corn (Bolanos and Edmeades, 1993; Azeez et al., 2005;

Efeoglu et al., 2009), kernel number per ear (Otegui et al., 1995; Zinselmeier et al., 1999; Boyer and Westgate, 2004) as well as thousand kernel weight (Weerathaworn et al., 1992) and hence potentially impact the feed value of corn silage since starch as a major constituent is primarily located in the grains. However, restricted irrigation did not affect the potential DM degradability of the incubated samples and, though significant, only low nominal effects on the kinetics of DM degradation and the estimated effective degradability were found. Furthermore, a slightly decreased effective ruminal DM degradability of corn silage, a feedstuff containing relatively slowly rumen degradable starch (Tothi et al., 2003; Matthe et al., 2003), does not necessarily indicate a reduced feed value. A potentially increased flooding of starch into the small intestine may result in a more efficient use of starch for milk synthesis than that digested in the rumen (Nocek and Tamminga, 1991). However, within the limits of the conducted analyses it is unknown which compounds contributed to the decreased effective degradability of the investigated silages grown under drought stress.

In corn, atmospheric CO<sub>2</sub> enrichment was reported to result in decreased plant water loss via stomatal conductance (Leakey et al., 2006) and an increase of the water use efficiency of biomass production (Manderscheid et al., 2011). That may lead to the hypothesis that atmospheric CO<sub>2</sub> elevation may reduce the negative effects of drought stress on corn growth and composition and hence indirectly improve the feed value of corn silage during periods of drought. However, this was not reflected in the examined parameters of DM degradation in the present experiment. No significant CO<sub>2</sub> × I interaction was observed for the effective degradability of silage DM and though significance was calculated for the potential degradability, the nominal effects were below 1 % unit. However, due to elevated CO<sub>2</sub> a slightly higher potential degradability was found during drought stress but it decreased if the plants were grown well watered. For harvest 3, the CO<sub>2</sub> control sample grown under drought stress was characterized by an unexplainable low starch but high fibre content in comparison to the other treatments and the previous harvest. These differences were not clearly explainable within the performed analyses and therefore incorrect sampling may have contributed to this effect.

Advancing maturity is accompanied by substantial changes in the chemical composition of corn since WSC levels in fresh whole plants were reported to decrease (Johnson et al., 2003; Filya et al., 2006), whereas starch concentration and DM percentage increase up to a certain limit (Browne et al., 2004; Browne et al., 2005; Mc Geough et al., 2010). In the present experiment, these alterations were reflected in significant effects on both kinetics and extent of ruminal degradability. Insoluble, but

degradable fraction and potential degradability increased gradually with later harvest. Both parameters were found to have close positive relationships to DM and starch content and were negatively correlated to silage fibre concentration, which is known to decrease with later harvest (Filya, 2004). These observations were consistent because increasing starch, but decreasing fibre contents will likely enhance the ruminal DM degradability of corn silage since ground corn grain was reported to be highly degradable exceeding 90 % after longer periods of incubation in the ovine forestomach (Flachowsky et al., 1992). Though the ruminal DM degradability of cobs does not necessarily increase with later harvest, their percentage of the whole plants rises and they are generally faster and to a greater extent degradable than stover (Akbar et al., 2002), which were shown to contain more fibre and to become less degradable with later harvest (Flachowsky et al., 1993). Nevertheless, these processes do not imperatively lead to an improved DM degradability of ensiled corn. Jochmann et al. (1999) compared both in sacco DM degradability and effective degradability of corn silages harvested at different maturity stages and did not observe significant differences between the incubated samples.

## 5 Conclusion

In the present experiment, the low effects of rising atmospheric CO<sub>2</sub> concentration and drought stress on the calculated parameters of in sacco DM degradation of corn silage did not indicate considerable alterations of the future feed value of ensiled whole corn plants grown under changed cultivation conditions. In contrast, harvest date influenced all evaluated degradation parameters and will likely remain an important factor determining feed value and ruminal degradability of corn silage.

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