# A comparison of the nutritive value of organically and conventionally grown barley and wheat crops

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# A comparison of the nutritive value of organically and conventionally grown barley and wheat crops

**M.L. Tejido*, M.J. Ranilla*, C. Palacios*, C. Saro*, A. Sosa**, A. Díaz** and M.D. Carro***

*Departamento de Producción Animal, Universidad de León, 24071 León (Spain).
Instituto de Ganadería de Montaña (CSIC-ULE), Finca Marzanas s/n. 24346 Grulleros, León (Spain)
**Instituto de Ciencia Animal, Apartado Postal 24, San José de las Lajas, La Habana (Cuba)

**Abstract.** The objective of this study was to investigate if there is any significant difference in yield and nutritive value between organically and conventionally grown wheat and barley crops. Each cultivation system was carried out in three plots of each crop bordering each other to assure similar soil properties. Both crops were harvested in May at post-bloom stage, and the whole plants were used for the analyses. The true in vitro digestibility of dry matter (IVDMD) and neutral-detergent fibre (IVNDFD) of the samples was determined after 24 h of incubation with buffered ruminal fluid. In addition, volatile fatty acid production and ammonia-N concentrations were determined after 24 h of incubation of samples with buffered ruminal fluid. Finally, samples (500 mg) of each substrate were incubated with 50 ml of buffered rumen fluid at 39ºC and gas production was measured at 3, 6, 9, 12, 16, 21, 26, 31, 36, 48, 60, 72, 96, 120 and 144 h. Gas production values were fitted to the exponential model: gas = A (1 – e $^{(-c\ (t-lag))}$), and the average gas production rate (AGPR; ml gas/h) was calculated. Data for each crop were analyzed independently. Organic cultivation decreased the yield of barley and wheat to 60 and 74%, respectively, of that in the conventional cultivation. No differences (P = 0.063 to 0.941) in organic matter, neutral-detergent fibre and acid-detergent fibre content were detected between cultivation systems, but crude protein content was lower (P ≤ 0.001) in organic compared with conventional cultivars (6.28 vs. 7.25% for barley and 5.23 vs. 6.69% for wheat). Organic and conventionally grown crops had similar (P = 0.297 to 0.857) IVDMD (57.1 vs. 57.6% for barley and 55.3 vs. 55.7% for wheat) and IVNDFD (24.1 vs. 24.7% and 20.5 vs. 20.7%). Regarding the gas parameters, only the rate of gas production of barley was decreased (P = 0.014) by organic cultivation, but no differences (P>0.05) were detected in the potential gas production, lag time or AGPR. For both cereals, there were no differences (P>0.05) between cultivation systems in final pH, total volatile fatty acids production or molar proportions of acetate, butyrate and propionate, which would indicate a similar fermentation pattern of conventional and ecological cultivars. The results indicate that organic cultivation, at least in the short term, does not necessarily result in reduced nutritive value, although it decreased the yield of both crops.

**Keywords.** Organic Cultivation – Chemical Composition – In vitro Digestibility – Gas Production.

**Comparaison de la valeur nutritive des cultures d'orge et de blé conventionnels et biologiques**

***Résumé.*** *L'objectif de cette étude a été d'étudier s'il y en a des différences significatives en rendement et en valeur nutritive entre des cultures d'orge et de blé conventionnels et biologiques. Chaque système de culture a été utilisé dans trois parcelles de terrain de chaque espèce contigus pour assurer des propriétés semblables de sol. Les deux cultures ont été récoltés en mai à l'étape après la floraison, et les plantes entières ont été employées pour les analyses. La digestibilité réelle in vitro de la matière sèche (IVDMD) et de la fibre neutre-détergente (IVNDFD) des échantillons a été déterminée après 24 h d'incubation avec du fluide du rumen tamponné. En outre, la production d'acides gras volatiles et les concentrations en N-ammoniacal ont aussi été déterminées après 24 h d'incubation. Finalement, des échantillons (500 mg) de chaque substrat ont été incubés avec 50 ml de fluide du rumen tamponné à 39ºC et la production de gaz a été mesurée à 3, 6, 9, 12, 16, 21, 26, 31, 36, 48, 60, 72, 96, 120 et 144 h. Les valeurs de production de gaz de ont été adaptées au modèle exponentiel : gaz = A (1 – e (–c (t–lag))), et la vitesse du production de gaz (AGPR ; ml gas/h) a été calculé. Des données pour chaque récolte ont été analysées indépendamment. La culture biologique a diminué le rendement d'orge et de blé à 60 et à 74%, respectivement du rendement dans la culture conven-*

*tionnelle. Aucune différence (P=0.063 à 0.941) dans la matière organique, la fibre neutre-détersive et le contenu acide-détersif de fibre n'a été détectée entre les systèmes de culture, mais la teneur en protéines brutes a été inférieure (P≤0.001) dans les biologiques comparés aux cultivars conventionnels (6.28 contre 7.25% pour l'orge et 5.23 contre 6.69% pour le blé). Les cultivars biologiques et conventionnels ont eu des IVDMD (57.1 vs 57.6% pour l'orge et 55.3 vs 55.7% pour le blé) et des IVNDFD (24.1 vs 24.7% et 20.5 vs 20.7%) similaires (P=0.297 à 0.857). Concernant les paramètres de gaz, seulement le taux de production de gaz de l'orge a été diminué (P=0.014) par la culture organique, mais aucune différence (P>0.05) a été détectée dans la production de gaz, le temps de latence ou l'AGPR potentiel. Pour les deux céréales, il n'y a eu aucune différence (P>0.05) entre les systèmes de culture dans le pH final, la production totale d'acides gras volatiles ou les proportions molaires d'acétate, de butyrate et de propionate, qui indiqueraient un modèle de fermentation semblable des cultivars conventionnels et biologiques. Les résultats indiquent que la culture biologique, au moins à court terme, n'a pas nécessairement comme conséquence la réduction de la valeur nutritive, bien qu'elle ait diminué le rendement des deux cultivars.*

***Mots-clés.*** *Culture biologique – Composition chimique – Digestibilité in vitro – Production de gaz.*

## I – Introduction

The interest of consumers in organically produced foods has markedly increased in the last decades. Organic products of animal origin are those produced under controlled conditions following the provisions of the Council Regulation (EC) No 834/2007 of 28 June 2007 on organic production and labelling of organic products. This Regulation establishes that livestock shall be fed with organic feed that meets the animal's nutritional requirements at the various stages of its development, although a part of the ration may contain feed from holdings which are in conversion to organic farming (Council Regulation (EC) No 834/2007). Rearing systems for herbivores are to be based on maximum use of grazing pasturage according to the availability of pastures in the different periods of the year, and at least 60% of the dry matter in daily rations of herbivores shall consist of roughage, fresh or dried fodder, or silage.

Organic farming in Spain has increased considerably over the past decade, and cereals and legumes are the main crops with an increase of about 10% per year (Gonzálvez, 2007). However, the productivity of crops in organic farming has frequently been shown to be lower compared to conventional farming (Berry *et al.*, 2002; Olesen *et al.*, 2007). As pointed out by Ryan *et al.* (2004), differences between organic and conventional agriculture are often reported without investigation of underlying mechanisms, and the management practices used in both cultivation systems and the environmental conditions between experiments/sites have resulted in a variety of results making attempts at generalisation regarding organic/conventional differences difficult. The objective of this study was to investigate possible differences in yield and nutritive value of organically and conventionally grown wheat and barley when cereals were cultivated in plots bordering each other to assure similar soil properties and environmental conditions.

## II – Materials and methods

### 1. Cultivation systems and sampling

The experiment was carried out in Fariza de Sayago, Zamora, Spain (41° 25' N; 6° 16' W; altitude 708 m) from August 2008 to July 2009. Mean monthly maximum and minimum temperatures and rainfall distribution over the experimental period are presented in Fig. 1. Two experimental plots were used, one for each cereal. The experimental plots were established on a sandy loam, acid and low fertility soil. Both plots have been organically cultivated for 3 years, and were fallow

for one year prior to the onset of the study. Each plot was divided in 6 subplots bordering each other, which were cultivated either organically (3 subplots) or conventionally (3 subplots). In April 2008 all the plots received sheep manure. In October 2008, organic seeds were sown in all plots (200 kg/ha) to avoid any effect of seeds characteristics. Conventional plots were fertilized NPK (8-15-15) at a rate of 100 kg/ha after sowing. In January 2009, conventional plots were treated with a chemical herbicide containing clorsulfuron (Belure®; 16 g/ha) and a mineral fertilizer containing 27% N (80 kg/ha). No herbicide or fertilizer treatment was applied to organic plots.

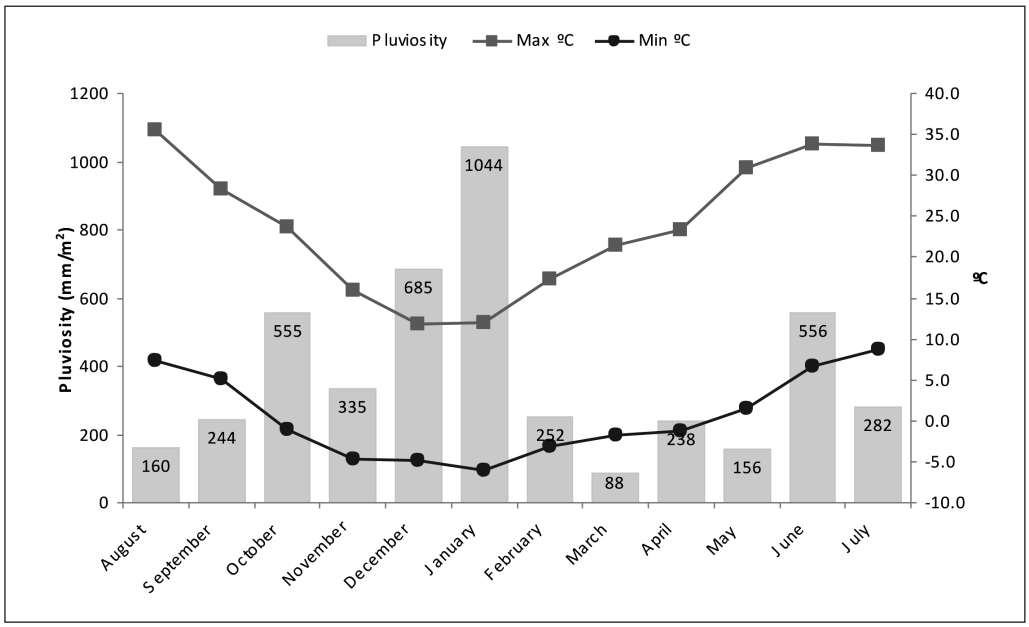


**Fig. 1. Monthly variation in rainfall (mm) and air temperature (ºC) over the experimental period.**

Whole-plant yield was determined in May 2009. Total above-ground biomass in a one square meter sampling area was taken on three areas per subplot. The collected samples were weighed and DM determined to estimate DM production. The three samples from the same subplot were mixed and ground (1-mm size) before determining their chemical composition and conducting the *in vitro* incubations.

At harvest time, soil samples were taken from each subplot (10 sampling points per plot) for determination of their pH and contents of N, P, Na, Ca, Mg, K, Fe, Mn and Zn. After air-drying of the samples their pH was measured with a pH meter in samples extracted either with water or with KCl. P content was determined as described by Olsen *et al.* (1954). Minerals were extracted as described by Ross and Wang (1993) and measured by inductively coupled plasma-atomic emission spectrometry (ICP-AES) using a ICP-AES Perkin Elmer Optima 2000 DV (Perkin Elmer, Überlingen, Germany).

## 2. *In vitro* fermentation of samples

Ruminal fluid was obtained from four rumen-cannulated Merino sheep fed 500 of grass hay and 500 g of concentrate per day administered in two equal portions at 08:00 and 20:00 h. Sheep were managed according to the protocols approved by the León University Institutional Animal Care and Use Committee. Ruminal contents of each sheep were obtained immediately before the morning feeding, mixed and strained through four layers of cheesecloth into an Erlenmeyer flask with an $O_2$-free headspace. Particle-free fluid was mixed with the buffer solution of Goering and Van Soest (1970; no trypticase added) in a proportion 1:4 (vol/vol) at 39ºC under continuous flushing with $CO_2$. Samples of 500 mg dry matter (DM) of each substrate were accurately weighed into 120-ml serum bottles and the bottles were prewarmed (39ºC) prior to the addition of 50 ml of buffered rumen contents into each one under $CO_2$ flushing. Bottles were sealed with butyl rubber stoppers and aluminium caps and incubated at 39ºC. A total of 12 bottles (one bottle per each substrate) were incubated for 24 h. At the end of the incubation period gas production was measured in each bottle using a pressure transducer and a calibrated syringe. Bottles were uncapped, the pH was measured immediately with a pH-meter, 0.5 ml of fluid were added to 0.8 ml of deproteinizing solution (100 g of metaphosphoric acid and 0.6 g of crotonic acid per L) for volatile fatty acid (VFA) analysis and 0.5 ml were added to 0.5 ml 0.5 *M* HCl for $NH_3$-N determination. Bottles were then recapped, and the fermentation was stopped by swirling the bottles in ice. Finally, the contents of the bottles were transferred to previously weighed filter crucibles, and the residue of incubation was washed with 50 ml of hot distilled water (50ºC). Crucibles were dried at 50ºC and weighed to calculate *in vitro* DM degradability (IVDMD). The residue was analysed for neutral detergent fibre (NDF) to calculate true IVDMD (TIVDMD; Van Soest *et al.*, 1966) and NDF degradability (IVNDFD). Two bottles containing only 50 ml of buffered rumen fluid (blanks) were included to correct gas production values for gas released from endogenous substrates. Each incubation run was repeated in four different days so that each determination was conducted in quadruplicate.

A total of 12 bottles (one bottle per each substrate) were incubated for 144 h. Gas production was measured at 3, 6, 9, 12, 16, 21, 26, 31, 36, 48, 60, 72, 96, 120 and 144 h as previously described and the gas produced was released after each measurement. After 144 h of incubation, the fermentation was stopped by swirling the bottles in ice, the bottles were opened and their content was transferred to previously weighed filter crucibles. The residue of incubation was washed with 50 ml of hot distilled water (50ºC), dried at 50ºC for 48 h and the apparent disappearance of substrate was calculated. The residue was then analysed for ash to calculate the organic matter (OM) apparent disappearance after 144 h of incubation ($OMD_{144}$). Two blanks were included to correct gas production values. Each incubation run was repeated in four different days so that each determination was conducted in quadruplicate.

## 3. Calculations, analytical procedures and statistical analyses

Gas production values were corrected for the gas amount of gas produced in the blanks and the values were fitted with time to the exponential model gas = $A\ (1 - e^{(-c\ (t-lag))})$, where $A$ is the asymptotic gas production, $c$ is the fractional rate of gas production, *lag* is the initial delay in the onset of gas production and t is the gas reading time. The parameters $A$, $c$ and *lag* were estimated by an iterative least squares procedure using the NLIN procedure of SAS (SAS Inst., Inc., Cary, NC, USA). The effective degradability of diet OM (OMED) was estimated assuming a rumen particulate outflow ($Kp$) of 0.04 per h, according to the equation proposed by France *et al.* (2000): $OMED = [(OMD_{144}\ c)/(c + Kp)]\ e^{(-\ c\ lag)}$. The average gas production rate (AGPR; ml gas/h) was defined as the average gas production rate between the start of the incubation and the time at which the cumulative gas production was half of its asymptotic value, and was calculated as $AGPR = A\ c\ /\ [2\ (\ln 2 + c\ lag)]$.

Dry matter, ash and N were determined according to the Association of Official Analytical Chemists (1999). Analyses of VFA and ammonia-N have been described by Carro and Miller (1999). Neutral-detergent fibre, acid-detergent fibre (ADF) and acid-detergent lignin analyses were carried out according to Van Soest *et al.* (1991) and Goering and Van Soest (1970), respectively. Data from each crop were analyzed independently by ANOVA with cultivation system as the main effect. Differences between treatments were declared significant at $P < 0.05$.

## III – Results and discussion

Table 1 shows the DM production and the chemical composition of barley and wheat cultivars. Yield of organic cultivars was 60 and 74% of that observed in conventional cultivars for barley and wheat, respectively, although differences between cultivation systems only reached the significance level ($P<0.05$) for barley. These results are in accordance with those reported by others for a wide range of cultivars (Mourão *et al.*, 2008; Casagrande *et al.*, 2009). Tamm *et al.* (2007) reviewed several comparative studies, and concluded that yield and protein content of wheat produced under organic standards was repeatedly shown to be between 20 and 40% lower than the levels achieved in conventional farming systems. In the present experiment, yield was reduced by 40 and 26% for barley and wheat, respectively.

**Table 1. Dry matter (DM) production (kg DM/ha) and chemical composition (g/kg DM) of conventional and organic barley and wheat crops**

| Crop | Cultivation system | DM production | Organic matter | Crude protein | Neutral-detergent fibre | Acid-detergent fibre | Acid-detergent lignin |
|---|---|---|---|---|---|---|---|
| **Barley** | Conventional | 4.23 | 944 | 72.5 | 564 | 232 | 34.8 |
| | Organic | 2.52 | 937 | 62.8 | 565 | 245 | 39.5 |
| | SEM | 0.314 | 2.4 | 0.85 | 8.6 | 5.6 | 2.56 |
| | *P* = | 0.029 | 0.166 | 0.001 | 0.941 | 0.178 | 0.282 |
| **Wheat** | Conventional | 3.12 | 950 | 66.9 | 558 | 259 | 41.4 |
| | Organic | 2.30 | 938 | 52.3 | 563 | 278 | 55.2 |
| | SEM | 0.477 | 7.25 | 1.08 | 6.7 | 5.2 | 6.26 |
| | *P* = | 0.294 | 0.299 | <0.001 | 0.606 | 0.063 | 0.196 |

No differences ($P>0.05$) in organic matter, NDF, ADF and acid-detergent lignin content of barley and wheat were detected between cultivation systems, but crude protein content was lower ($P\leq0.001$) in organic compared with conventional cultivars for both crops (62.8 *vs.* 72.5 g/kg DM for barley, and 52.3 *vs*. 66.9 g/kg DM for wheat). The lower organic yields and crude protein contents compared with conventional ones have been attributed, among other factors such as greater weed competition, lower nutrient use efficiency, and poorer control of pests and crop diseases (Kirschmann *et al.*, 2007), to N deficiency. However, as shown in Table 2 the N content in soil was not affected ($P>0.05$) by the cultivation system in any crop. No effects ($P=0.067$ to 0.998) of cultivation system were found either in soil pH or mineral contents in the barley plots. In contrasts, for wheat organic plots had greater contents of Ca ($P=0.015$), Mg ($P=0.007$) and Zn ($P=0.050$), and lower Na concentrations ($P=0.040$) compared with conventional plots. These results indicate that the influence of cultivation system on soil composition may be affected by the crop.

As shown in Table 3, organic and conventionally grown crops did not differ ($P$=0.11 to 0.35) in their *in vitro* dry matter digestibility, which is in agreement with the lack of differences observed in their chemical composition, with the exception of crude protein content. The values of gas production parameters ($A$, $c$ and *lag*) and of the calculated AGPR and OMED are also shown in Table 3. Organic barley showed lower values of gas production rate ($P$=0.014) and OMED ($P$=0.018) compared with barley grown conventionally, but no differences ($P$=0.192 to 0.618) were observed in $A$, *lag* or AGPR. For wheat, no differences ($P$=0.091 to 0.747) due to the cultivation method were observed in any of the measured parameters.

The values of the main fermentation parameters for conventional and organic samples are shown in Table 4. Organic barley showed lower values of other VFA concentrations ($P$=0.006) and tended to show lower values of $NH_3$-N concentration ($P$=0.075) compared with barley grown conventionally, which is in agreement with the lower N content observed in the organic samples. In contrast, no differences ($P$=0.113 to 0.871) in ruminal fermentation parameters due to the cultivation method were observed for wheat.

## IV – Conclusions

The results indicate that organic cultivation of barley and wheat reduced crop yield and protein content compared with conventional cultivation system. However, little effects of the cultivation system were observed on *in vitro* ruminal degradation of forages, which indicates that crops from both cultivation systems might have a similar digestive utilization. The possibility of increasing the yield and protein content of cereal crops in organic cultivation systems by improving fertility management practices should be investigated.

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**Table 2. Soil characteristics of conventional and organic plots after harvesting barley and wheat (n = 3)**

| | Barley | | | | Wheat | | | |
|---|---|---|---|---|---|---|---|---|
| **Item** | **Conventional** | **Organic** | **SEM** | ***P* =** | **Conventional** | **Organic** | **SEM** | ***P* =** |
| pH (water) | 6.17 | 6.26 | 0.118 | 0.630 | 5.48 | 5.77 | 0.102 | 0.116 |
| pH (KCl) | 5.29 | 5.39 | 0.041 | 0.145 | 4.44 | 4.75 | 0.111 | 0.115 |
| N (g/kg) | 1.38 | 1.26 | 0.049 | 0.162 | 0.92 | 0.82 | 0.054 | 0.277 |
| Minerals (mg/kg) | | | | | | | | |
| P | 68.5 | 65.0 | 1.25 | 0.123 | 44.9 | 47.3 | 1.44 | 0.294 |
| Na | 0.063 | 0.017 | 0.0132 | 0.067 | 0.043 | 0.015 | 0.0066 | 0.040 |
| Ca | 3.26 | 3.30 | 0.155 | 0.853 | 0.92 | 1.54 | 0.108 | 0.015 |
| Mg | 0.65 | 0.65 | 0.033 | 0.998 | 0.17 | 0.26 | 0.014 | 0.007 |
| K | 0.49 | 0.52 | 0.022 | 0.448 | 0.22 | 0.29 | 0.026 | 0.127 |
| Cations (cmol(+)/kg) | | | | | | | | |
| Fe | 132 | 120 | 9.53 | 0.412 | 32.9 | 54.5 | 7.59 | 0.114 |
| Mn | 12.1 | 12.3 | 1.55 | 0.933 | 11.0 | 14.2 | 4.55 | 0.646 |
| Zn | 2.12 | 2.08 | 0.168 | 0.875 | 0.89 | 1.45 | 0.014 | 0.050 |

**Table 3. Values of *in vitro* degradability and parameters of gas production kinetics of conventional and organic barley and wheat crops**

| | Barley | | | | Wheat | | | |
|---|---|---|---|---|---|---|---|---|
| **Item** | **Conventional** | **Organic** | **SEM** | ***P* =** | **Conventional** | **Organic** | **SEM** | ***P* =** |
| *In vitro* degradability† | | | | | | | | |
| IVDMD | 69.3 | 67.7 | 0.87 | 0.272 | 70.2 | 67.8 | 0.85 | 0.111 |
| TIVDMD | 74.4 | 72.9 | 0.73 | 0.209 | 74.5 | 73.3 | 0.67 | 0.260 |
| IVNDFD | 54.6 | 52.0 | 0.74 | 0.068 | 54.3 | 52.5 | 0.84 | 0.215 |
| Parameters of gas production†† | | | | | | | | |
| *A* | 329 | 332 | 4.4 | 0.618 | 321 | 316 | 8.9 | 0.701 |
| *c* | 0.0343 | 0.0326 | 0.00043 | 0.014 | 0.0346 | 0.0348 | 0.00080 | 0.506 |
| *Lag* | 0.70 | 0.56 | 0.131 | 0.457 | 0.17 | 0.13 | 0.079 | 0.747 |
| AGPR | 7.85 | 7.61 | 0.109 | 0.192 | 7.94 | 7.90 | 0.150 | 0.500 |
| OMED | 35.5 | 34.4 | 0.29 | 0.018 | 35.8 | 34.8 | 0.39 | 0.091 |

† IVDMD: in vitro dry matter degradability; TIVDMD: true IVDMD; IVNDFD: *in vitro* neutral-detergent fibre degradability.

†† *A:* asymptotic gas production (ml/500 mg DM sample); *c:* fractional rate of gas production ($h^{-1}$); *lag:* initial delay in the onset of gas production (h); AGPR: average gas production rate (ml/h); OMED: organic matter effective degradability (%).

**Table 4. Values of final pH, concentrations of $NH_3$-N (mg/l) and total volatile fatty acids (VFA; µmol/500 mg DM sample) and molar proportions of individual VFA (mol/100 mol) of conventional and organic barley and wheat samples incubated in batch cultures of rumen micro-organisms for 24 h (n = 4)**

| | Barley | | | | Wheat | | | |
|---|---|---|---|---|---|---|---|---|
| **Item** | **Conventional** | **Organic** | **SEM** | ***P* =** | **Conventional** | **Organic** | **SEM** | ***P* =** |
| pH | 6.71 | 6.70 | 0.005 | 0.121 | 6.69 | 6.71 | 0.004 | 0.113 |
| $NH_3$-N | 262 | 247 | 5.6 | 0.075 | 264 | 256 | 4.1 | 0.184 |
| Total VFA | 2727 | 2614 | 31.4 | 0.020 | 3792 | 2746 | 35.7 | 0.373 |
| Molar proportion of: | | | | | | | | |
| Acetate | 60.2 | 60.9 | 0.52 | 0.254 | 61.7 | 62.0 | 0.48 | 0.654 |
| Propionate | 25.6 | 24.9 | 0.38 | 0.104 | 26.5 | 26.2 | 0.25 | 0.415 |
| Butyrate | 12.1 | 12.5 | 0.25 | 0.317 | 10.2 | 10.2 | 0.21 | 0.871 |
| Others† | 2.09 | 1.71 | 0.086 | 0.006 | 1.56 | 1.51 | 0.080 | 0.659 |

† calculated as the sum of isobutyrate, isovalerate, valerate and caproate.

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