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**Macromineral and trace element concentrations and their seasonal variation in
milk from organic and conventional dairy herds**

Running title: Mineral concentrations in organic and conventional farm milk

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Abstract

To study the effects of dairy production system on milk macromineral and trace element concentrations, milk samples were collected monthly in 2019 from 43 conventional and 27 organic farms. Organic milk contained more Ca (1049.5 vs. 995.8 mg/kg), K (1383.6 vs. 1362.4 mg/kg), P (806.5 vs. 792.5 mg/kg) and Mo (73.3 vs. 60.6 µg/kg) but less Cu (52.4 vs. 60.6 µg/kg), Fe (0.66 vs 2.03 mg/kg), Mn (28.8 vs. 45.0 µg/kg), Zn (4.51 vs. 5.00 mg/kg) and Al (0.32 vs. 1.14 µg/kg) than conventional milk. Significant seasonal variation was observed in all determined minerals' concentrations. Milk I concentration was not consistently affected by production system, whereas organic milk contained less I in June and July than conventional milk. Dietary factors contributing to different milk mineral concentrations between production systems included intakes of maize silage, dry-straights and oils (higher in conventional diets), and pasture, clover and wholecrop (higher in organic diets).

Keywords: dairy cow, milk, organic, minerals, macrominerals, trace elements, heavy metals, iodine, production system

16

1. Introduction

17 Organic farming promotes the use of naturally produced substances and processes and limits
18 the application of chemically synthesised ingredients. In organic dairy farming, cows consume
19 more pasture and lower amounts of concentrate feeds and additives when compared with those
20 managed in conventional production systems (Weller & Bowling, 2007). As a consequence of
21 differences in cow nutrition, the chemical composition and nutritional value of organically
22 produced milk, including contents of saturated fat, n-3 fatty acids, trans fatty acids, tocopherols,
23 antioxidants and minerals, may differ from those of conventionally produced milk (Schwendel
24 et al., 2015; Stergiadis et al., 2012).

25 The difference in mineral composition between organic and conventional milk has been
26 reported based on data from various European countries (Poulsen, Rybicka, Poulsen, Larsen,
27 Andersen, & Larsen, 2015; Rey-Crespo, Miranda, & Lopez-Alonso, 2013). These differences
28 in minerals can be attributed to (i) the mineral status of organically managed cows reflecting
29 local environmental conditions when compared with conventionally managed cows, usually as
30 a consequence of their greater reliance on grazing rather than conserved forage (Orjales,
31 Herrero-Latorre, Miranda, Rey-Crespo, Rodriguez-Bermudez, & Lopez-Alonso, 2018) and (ii)
32 the limited (if any) mineral supplementation to organically managed cattle. These organic
33 farming practices are considered as factors that reduce the concentrations of some essential
34 trace elements in milk, with I and Se being the most commonly reported ones (Srednicka-Tober
35 et al., 2016; van de Kamp, Saridakis, & Verkaik-Kloosterman, 2019).

36 Organic systems may conversely affect the concentrations of toxic heavy metal elements in
37 milk, as reported previously that organic milk contains less As and Cr, but more Cd than
38 conventional milk (Lopez-Alonso, Rey-Crespo, Herrero-Latorre, & Miranda, 2017;
39 Rodriguez-Bermudez, Lopez-Alonso, Miranda, Fouz, Orjales, & Herrero-Latorre, 2018). The
40 differences in heavy metal concentrations are contributed by the greater ingestion of soil by

41 organically managed cows during grazing when compared with their conventional counterparts
42 (Lopez-Alonso et al., 2017).

43 In addition, organic milk has been reported to have greater seasonal variation in mineral
44 composition than conventional milk (van de Kamp et al., 2019). The seasonal variation in
45 organic milk mineral composition is attributed to the inconsistency in pasture intake of
46 organically managed cows during a year. Moreover, pasture intake is known to be correlated
47 with the concentrations of a number of minerals in milk, for instance, it increases Ni and
48 reduces Cu and I concentrations (O'Brien et al., 1999). In contrast, the diets of conventionally
49 managed cows may be more homogeneous throughout the year, which results in more
50 consistent mineral composition of milk between seasons.

51 Since cow milk is an important source of a number of essential nutrients for human, variation
52 in mineral composition between production systems and different seasons potentially impacts
53 mineral supply and balance of consumers. Although data regarding other minerals are scarce,
54 previous works on milk iodine concentration have reported that consumption of organic milk
55 could reduce iodine intake of the UK population, with potential implications particular in sub-
56 groups with higher requirements, e.g., pregnant women (Bath, Button, & Rayman, 2012).
57 Given that I deficiency is observed in 23% of women 11-18 years old and 10% of women 19+
58 years old (Miller, Spiro, & Stanner, 2016), it was previously claimed that consumption of
59 organic milk may further reduce the chance of these age groups to meet their requirements.
60 However, there has been limited systematic analyses of husbandry practices at a farm level that
61 may influence milk mineral concentrations, as well as implications these might have for human
62 nutrition when taking into account a wider range of minerals from organic and conventional
63 milk.

64 The objectives of the current study were to (i) compare the macromineral and trace element
65 profiles of organic and conventional milk produced in Southern England and their variation

66 throughout the year, (ii) identify husbandry practices (management, breeding, diet) that impact
67 milk macromineral and trace element concentrations and (iii) estimate the impact that
68 differences between organic and conventional milk macromineral and trace element profiles
69 may have on consumers' mineral intakes. It was hypothesised that the concentrations of
70 specific macrominerals and trace elements differ between organic and conventional milk and
71 the difference in milk mineral composition between production systems mainly results from
72 cow diet and herd breeding parameters.

73 **2. Materials and Methods**

74 *2.1 Experiment/survey design*

75 The current study presents results from 809 milk samples collected from 70 dairy herds in
76 Southern England. Twenty-seven of the farms were certified organic according to Soil
77 Association or Organic Farmers and Growers standards, including 11 farms applying all-year
78 round calving, nine farms applying autumn calving, three farms applying spring and autumn
79 calving and four farms applying spring calving. The remaining 43 farms were non-organic
80 (conventional), among which autumn calving, spring and autumn calving and spring calving
81 were applied in one farm, respectively, and all-year round calving was applied in the rest.
82 Although regulations for organic certification may differ between countries across the world,
83 organic dairy diets are generally associated with higher intakes of pasture, forage:concentrate
84 ratios and contribution of legumes in the pastures and conserved forages; with considerable
85 within-system variation being also apparent (Stergiadis et al., 2015; Stergiadis et al., 2012). In
86 the present work, both organic and conventional farms allowed access to outdoors/pasture
87 during the grazing season (March-October), and the average grazing intake throughout the year
88 was 25% of dry matter intake (DMI) in the organic and 8% in the conventional herds, with
89 maximum average across-farms pasture intake being observed in April for organic herds (58%

90 DMI) and July (16% DMI) for the conventional herds. Over the study, concentrate feeds
91 represented 26% DMI and 39% DMI in the organic and conventional herds, respectively. In
92 conventional production system, pastures and silages were predominantly perennial ryegrass,
93 while in organic systems silage typically has variant grass:clover ratios. Both production
94 systems kept Holstein and non-Holstein breeds, and the latter averaged at 36% and 21% in the
95 organic and conventional herds, respectively. Detailed analysis of the herd composition and
96 feed intake in conventional and organic farms is presented in Table 1.

97 Milk was collected monthly (3rd week in each month) from farms' bulk tanks following stirring
98 between January and December 2019. Corresponding herd breeding records (proportion of
99 each breed/crossbreed in the herd) and feeding practices (type/amounts of conserved forage,
100 other feeds, supplements offered) were collected during each sampling session, using
101 questionnaires completed collaboratively by each producer and an interviewer. Average herd
102 live weights were estimated based on average breed live weights (supplementary Table S1) and
103 the proportionate number of cows from each breed/crossbreed in the total herd, as described
104 by Stergiadis et al. (2018). Estimated DMI and pasture intake were calculated based on average
105 breed live weight and recorded milk yield, according to Butler et al. (2008).

106 *2.2 Milk analysis*

107 Following collection, milk samples were kept cool and transferred to the laboratory where each
108 sample was aliquoted into three 7 mL containers, one remained refrigerated and two were
109 frozen at -20°C. The chilled aliquot was sent to National Milk Laboratories (Wolverhampton,
110 UK) for analysis of fat, protein and lactose by Fourier Transform InfraRed spectroscopy
111 (MilkoScanTM 7RM; FOSS, Denmark) and somatic cell count (SCC) by flow cytometry
112 (FossomaticTM 7; FOSS, Denmark).

113 The frozen aliquots were lyophilised at the University of Reading and sent on ice to Matis
114 (Reykjavik, Iceland) for analysis of Al, As, Ca, Cd, Co, Cr, Cu, Fe, Hg, I, K, Mg, Mn, Mo, Na,
115 Ni, P, Pb, Se, Sn and Zn. The samples were digested using an Ultra-wave Acid Digestion
116 System (Milestone Inc., Italy) and then proceed to macromineral and trace element analyses
117 using inductively coupled plasma mass spectrometry (Agilent 7900, Agilent Technologies,
118 Singapore). The analysis of I was performed according to the method described by Payling et
119 al. (2015). Analyses of Al, As, Ca, Cd, Co, Cr, Cu, Fe, Hg, K, Mg, Mn, Mo, Na, Ni, P, Pb, Se,
120 Sn and Zn were performed according to an NMKL method (NMKL 186, 2007).

121 *2.3 Statistical analysis*

122 Analyses of variance were performed with a mixed linear model (residual maximum likelihood
123 analysis; REML) in GenStat (VSN International, 18th Edition, Hempstead, UK). The fixed
124 effects included production system (Conventional, CON; Organic, ORG), month (January,
125 February, March, April, May, June, July, August, September, October, November, December)
126 and the interaction between them. Farm ID was included as a random effect. In all analyses,
127 normality plots were used to assess the residual diagnostics of the final model. Mineral
128 concentrations and SCC were $\log(x+1)$ and $\log(x)$ transformed, respectively, prior to REML
129 analysis. Descriptive statistics, to generate means and standard errors, were performed in
130 untransformed data. When the fixed effect was significant ($p < 0.05$), pairwise comparisons of
131 means were performed using Fisher's Least Significant Difference test.

132 Multivariate redundancy analysis (RDA) was performed to assess the relative impact of breed
133 and diet composition on milk yield, basic composition and macrominerals and trace elements,
134 using CANOCO 5 Windows Release 5.12, with the automatic forward selection of variables
135 and significances calculated using Monte Carlo permutation tests. In the RDA biplots, arrow
136 length and direction represent the relative effects of driver variables (herd breed and diet
137 composition parameters) on the response variables (milk yield, basic composition and mineral

138 profile). The driver related to breed represents the proportion of non-Holstein genetics in the
139 herd (the summary of British Friesian, NZ Friesian, Jersey, Scandinavian Red, Shorthorn,
140 Ayrshire, Brown Swiss, Guernsey and other breed/crossbreed). Drivers related to nutrition
141 were dietary proportions of estimated grazing, grass/grass-clover silage, maize silage, lucerne
142 silage, other mixed silage, wholecrop (ensiled whole wheat plants, harvested approximately 1
143 month before grain maturity), hay/straw, moist by-products, dry straights, cereals, blends, oil,
144 minerals and vitamins. The response variables included milk yield, basic composition (fat,
145 protein, lactose and SCC) and concentrations of minerals (Al, Ca, Cu, Fe, I, K, Mg, Mn, Mo,
146 Na, P, Sn, Zn).

147 **3. Results**

148 *3.1 Herd composition and feed intake*

149 The conventional and organic farms had similar herd compositions, with Holstein being the
150 major breed comprising more than 60% of total cows in both systems (Table 1). There was
151 significant but numerically minor difference between production systems in the proportions of
152 Scandinavian Red ($p = 0.019$) and Shorthorn ($p = 0.002$), being marginally higher in organic
153 farms than conventional farms, although in both cases their contribution to the total herd was
154 <1%.

155 Estimated daily DMI was higher in conventional farms than in organic farms ($p < 0.001$; Table
156 1). Significant difference between production systems was also observed in almost all diet
157 composition parameters (expressed as % DMI). Conventionally managed cows had a lower
158 total forage intake ($p < 0.001$) and a higher total concentrate intake ($p < 0.001$) when compared
159 with organically managed cows. Intake of maize silage ($p < 0.001$) was higher in conventional
160 farms than in organic farms. In contrast, intakes of grass/grass-clover silage ($p < 0.001$), other
161 mixed silage ($p < 0.001$) and wholecrop silage ($p < 0.001$) were lower in conventional farms

162 than in organic farms. When compared with conventional farms, organic farms fed cows lower
163 amounts of moist by-products ($p < 0.001$), dry straights ($p < 0.001$), oils ($p < 0.001$) and
164 minerals ($p = 0.007$). In addition, total concentrate intake ($p = 0.004$), grazing intake ($p < 0.001$)
165 and intakes of grass/grass-clover silage ($p < 0.001$) and maize silage ($p < 0.001$) showed
166 significant monthly variation (supplementary Figure S1). Significant interactions between
167 production system and month were observed in grazing ($p < 0.001$), grass/grass-clover silage
168 ($p < 0.001$) and maize silage ($p < 0.001$) intakes (supplementary Figure S1).

169 *3.2 Milk yield and composition*

170 Average milk yield was considerably higher in conventional production system (+7.3 kg/cow/d;
171 $p < 0.001$) with slightly higher milk lactose content (+0.4 g/kg milk; $p = 0.009$) when compared
172 with organic production system (Table 2). Average milk fat, protein and SCC contents were
173 not different between production systems. Significant interactions between production system
174 and month were observed in milk yield ($p = 0.010$) and contents of fat ($p = 0.005$), protein (p
175 < 0.001) and lactose ($p < 0.001$; supplementary Figure S2). The within-month comparisons
176 showed that when compared with organic farms, conventional farms had greater milk yields (p
177 < 0.05) in all months; higher milk lactose contents ($p < 0.05$) in January, June, July, August
178 and September; a lower milk fat content ($p < 0.05$) in September; and a lower milk protein
179 content ($p < 0.05$) in August.

180 Across production systems, milk yield and composition fluctuated markedly over time (time
181 effect $p < 0.05$; Table 3). Milk yields in April and May were greater ($p < 0.05$) than in other
182 months. Milk fat and protein contents decreased from January and reached their lowest levels
183 during summer, followed by a gradual increase thereafter. Milk lactose content remained
184 relatively stable from January to June and declined marginally thereafter. Milk SCC was
185 noticeably lower ($p < 0.05$) in February and September when compared with other months.

186 *3.3 Milk macromineral and trace element concentrations*

187 Of the determined macrominerals, organic milk contained higher average concentrations of Ca
188 (+53.7 mg/kg milk, $p < 0.001$), K (+21.2 mg/kg milk, $p = 0.048$) and P (+14.0 mg/kg milk, p
189 = 0.042) than conventional milk (Table 2). Significant interactions between production system
190 and month were observed in the concentrations of K ($p < 0.001$) and P ($p < 0.001$; Figure 1).
191 In January, the concentrations of K and P in conventional milk were higher ($p < 0.05$) than
192 those in organic milk, while the opposite ($p < 0.05$) was observed in August, October and
193 November for K and in April and August for P. Regardless of production system,
194 concentrations of Ca, K, Na, Mg and P shared a similar pattern over time (Table 3). Their
195 concentrations increased from January to March and remained stable thereafter except for a
196 sharp decrease in June.

197 Of the determined essential trace elements, conventional milk contained higher average
198 concentrations of Cu (+8.2 $\mu\text{g}/\text{kg}$ milk, $p < 0.001$), Fe (+1.3 mg/kg milk, $p < 0.001$), Mn (+16.2
199 $\mu\text{g}/\text{kg}$ milk, $p < 0.001$) and Zn (0.5 mg/kg milk, $p < 0.001$) when compared with organic milk,
200 while the opposite was observed for milk Mo concentration (-12.7 $\mu\text{g}/\text{kg}$ milk, $p < 0.001$; Table
201 2). Average milk I concentration was not significantly affected by production system. In the
202 analyses of Co and Se, 78% and 84% of the individual measurements were below the limits of
203 quantification (Co, 0.59 $\mu\text{g}/\text{kg}$ milk; Se, 35.38 $\mu\text{g}/\text{kg}$ milk), respectively, and these results were
204 not included in the statistical analysis. Significant interactions between production system and
205 month were observed in milk concentrations of Cu ($p < 0.001$), Fe ($p < 0.001$), I ($p < 0.001$),
206 Mn ($p < 0.001$), Mo ($p < 0.001$) and Zn ($p < 0.001$; Figure 2). Comparisons within months
207 suggested that conventional milk had a higher ($p < 0.05$) Cu concentration in January, March,
208 May, July and August, but a lower ($p < 0.05$) Cu concentration in February and September,
209 when compared with organic milk. Milk I concentration was higher ($p < 0.05$) in conventional
210 milk than organic milk in June and July. The concentrations of Fe, Mn and Zn were greater (p

211 < 0.05) in conventional milk than organic milk in January, March, July and August, while
212 conventional milk had a lower ($p < 0.05$) Fe concentration in February and lower ($p < 0.05$) Zn
213 concentrations in February and September when compared with organic milk. In addition,
214 organic farms produced milk containing more ($p < 0.05$) Mo in February, April, June,
215 September, October, November and December, when compared with conventional production
216 system, while the opposite effect ($p < 0.05$) was observed in July and August. Across
217 production systems, milk Cu, Mo and Zn concentrations were higher between January and
218 March when compared with the other months. Their concentrations were relatively stable
219 between April and December except that higher ($p < 0.05$) concentrations were observed in
220 conventional milk than organic milk in July and August (Table 3 and Figure 2). The
221 concentrations of Fe and Mn in milk were lowest between April and June and then peaking in
222 July. Milk I concentration was markedly lower in summer than in winter, presented as a gradual
223 decrease from March to May, before increasing in July, a trend that persisted for the remainder
224 of the year.

225 Most non-essential trace and toxic heavy metal elements (including As, Cd, Cr, Hg, Ni and Pb)
226 were present in low concentrations and the majority of their individual measurements was
227 below the limits of quantification (As, 5.90 $\mu\text{g}/\text{kg}$ milk; Cd, 0.24 $\mu\text{g}/\text{kg}$ milk; Cr, 7.08 $\mu\text{g}/\text{kg}$
228 milk; Hg, 2.36 $\mu\text{g}/\text{kg}$ milk; Ni, 4.72 $\mu\text{g}/\text{kg}$ milk; Pb, 8.26 $\mu\text{g}/\text{kg}$ milk): As (99%), Cd (57%), Cr
229 (81%), Hg (100%), Ni (88%), Pb (99%). The results of these elements were thus not included
230 in statistical analysis. Of the accurately quantified elements, conventional milk had a higher (p
231 < 0.001) average Al concentration (+0.8 mg/kg milk) than organic milk (Table 2). In addition,
232 the concentrations of Al ($p < 0.006$) and Sn ($p < 0.001$) showed significant interactions between
233 production system and month (Figure 1). The within-month comparisons showed that
234 conventional milk contained more ($p < 0.05$) Al than organic milk in January, March and July.
235 The interaction in Sn concentration was characterized by a higher ($p < 0.05$) Sn concentration

236 in January and March and a lower ($p < 0.05$) Sn concentration in February and July in
237 conventional milk when compared with organic milk. Across production systems, significant
238 time effects were observed in the concentrations of Al ($p < 0.001$) and Sn ($p < 0.001$; Table 3).
239 Milk Al concentration was significantly higher ($p < 0.05$) in January, March and July when
240 compared with other months. The concentration of Sn fluctuated throughout the year and had
241 its minimum between June and September.

242 *3.4 Effect of breeding and diet parameters*

243 The RDA examined relationships between driver variables related to cow breed and diet
244 compositions and response variables including milk yield, composition and mineral
245 concentrations (Figure 3). Drivers explained 7.9% of the variation, of which 4.2% was
246 explained by axis 1 and a further 2.1% was explained by axis 2. Estimated grazing intake and
247 maize silage intake accounted for 3.3% and 1.3% of the total explained variation, while all
248 other feed ingredients and breed individually accounted for less than 1% of the variation. Milk
249 yield and concentrations of lactose, Al, Cu, Fe Mn, Sn and Zn, and to a lesser extent Sn, were
250 positively correlated with intakes of maize silage, dry straights, oils, minerals and hay/straw;
251 and negatively correlated with intakes of pasture, total forage and alternative (non-Holstein)
252 breeds. Milk yield and concentrations of lactose, Al and Fe were also positively correlated with
253 intakes of moist by-products. Milk SCC was positively correlated with intakes of moist by-
254 products, oils, maize silage and pasture and negatively correlated with intakes of grass/grass-
255 clover silage, cereals, wholecrop and to a lesser extent with hay/straw. On the contrary, milk
256 concentrations of protein, Ca, P, K and Na were negatively correlated with intakes of maize
257 silage, dry straights, minerals, oils and moist-by products (Na was not correlated with moist
258 by-products); and positively correlated with grazing and total forage intakes and the proportion
259 of alternative (non-Holstein) breeds. Milk Ca content was also positively correlated with
260 wholecrop, cereals and grass/grass-clover silage intakes. Concentration of I was negatively

261 correlated with grazing and total forage intakes, as well as alternative (non-Holstein breeds)
262 and positively correlated with intakes of grass/grass-clover silage, cereals, wholecrop, dry
263 straights and minerals, and to a small extent with hay/straw. Milk concentrations of fat and Mo
264 were positively correlated with intakes of cereals, grass/grass-clover silage, wholecrop, total
265 forage and the proportion of alternative (non-Holstein) breed, while Mg was positively
266 correlated only with intakes of cereals, grass/grass-clover silage and wholecrop. Milk contents
267 of fat and Mo were negatively correlated with intakes of moist by-products, oils, maize silage
268 minerals and dry straights.

269 **4. Discussion**

270 *4.1 Milk yield and basic composition*

271 *4.1.1 Effects of production system on milk yield and basic composition*

272 Organic farms produced 25% less milk per cow than conventional farms. Decreased milk yield
273 in organic production system has been reported a number of times in previous studies
274 (Stergiadis et al., 2015; Stergiadis et al., 2012), in which 15-30% less milk production was
275 observed in organic farms than conventional farms. The reduced milk production by the
276 organic farms has been mainly associated with the lower intake of concentrates and higher
277 intake of pasture, thus resulting in a lower energy density diet (Schwendel et al., 2015). The
278 reduction of diet energy also gives rise to the necessity to use alternative breeds to Holstein
279 (Stergiadis et al., 2015; Stergiadis et al., 2012). In the present study, total concentrate intake
280 was considerably lower in organic farms than in conventional farms, while pasture and forage
281 intakes were higher. The results of the RDA confirmed the strong negative correlation of milk
282 yield with total forage and grazing intakes as well as the proportion of alternative (non-Holstein)
283 breeds, and the positive correlation with intakes of maize silage and some concentrate
284 ingredients (in particular oils, dry straights, moist by-products and minerals), with some of

285 these findings previously demonstrated (Stergiadis et al., 2012). In addition, previous work
286 reported that milk yield in organic farms may be also limited by farmers in order to reduce
287 production intensity and the incidence of mastitis (Valle, Lien, Flaten, Koesling, & Ebbesvik,
288 2007).

289 Milk fat content was not consistently affected by production system, although there was a
290 higher fat content in organic milk when compared with conventional milk in September.
291 Previously, contradictory results from the comparison of milk fat content between different
292 production systems have been reported (Butler et al., 2008; Sundberg, Berglund, Rydhmer, &
293 Strandberg, 2009). Schwendel et al. (2015) suggested that a higher fat content in organic than
294 conventional milk can be expected because the greater intakes of starch-based concentrates in
295 conventional farms may reduce milk fat synthesis. In addition, findings of the RDA and other
296 studies suggest that the higher contribution of alternative breeds in the herd may also contribute
297 to the higher fat content of organic milk (Palladino, Buckley, Prendiville, Murphy, Callan, &
298 Kenny, 2010; Stergiadis et al., 2015). In the present study, the difference in concentrate intake
299 between production systems was greater during the grazing season (April – September)
300 compared with other months, which may explain the higher milk fat content of organic milk at
301 the end of the grazing season, while the potential impact of breed would be minimal due to the
302 relatively similar breed make-up of the conventional and organic herds.

303 The influence of production system on milk protein content was also minor, as only
304 characterized by a higher protein content of organic milk in August. Milk protein content was
305 suggested to be positively associated with intake of starch-based concentrate (Rius et al., 2010)
306 and higher protein contents of conventional milk than organic milk have been previously
307 reported by others (Sundberg et al., 2009). However, similar results were not observed in the
308 present study even though a considerably higher level of concentrate was involved in the diets
309 of conventional managed cows compared with those of their organic counterparts. The similar

310 breed make-up of conventional and organic herds may also explain the similarities in milk
311 protein content, as breed is also a strong driver for milk protein content, according to previous
312 studies (Palladino et al., 2010; Stergiadis et al., 2015) and the RDA results in the current study.
313 Milk lactose content was marginally lower in organic production system when compared with
314 conventional system. The reduction of milk lactose content in organic milk occurred mainly
315 during the grazing season (June – September). Previously, a lower lactose content in organic
316 milk than in conventional milk has been reported by others (Tunick, Van Hekken, Paul, Ingham,
317 & Karreman, 2016). As milk lactose content has been reported to be increased by infusion of
318 starch to cows (Rius et al., 2010), the reduction in organic milk lactose content during the
319 grazing season may be explained by the enlarged difference in concentrate intake between
320 production systems (higher in conventional) during this period. The RDA revealed positive
321 correlations between intakes of maize silage, oils, dry straights and minerals and milk lactose
322 concentration. Therefore, the lower intakes of these feeds in organic herds may have also
323 contributed to the slightly lower lactose content of milk.

324 *4.1.2 Seasonal variation of milk composition*

325 Across production systems, milk fat and protein contents showed a similar pattern over time;
326 their concentrations were higher in winter and lower in summer. Previously, the reduction of
327 milk fat and protein contents from winter to summer have been reported by others (Bernabucci
328 et al., 2015; Heck, van Valenberg, Dijkstra, & van Hooijdonk, 2009). The seasonal variation
329 in milk fat and protein contents is likely associated with grazing, as a previous study showed
330 that milk fat decreased linearly with increased fresh grass intake (Couvreur, Hurtaud, Lopez,
331 Delaby, & Peyraud, 2006). The lipid in fresh pasture contains a relatively high level of long-
332 chain unsaturated fatty acids, exemplified by linolenic acid, as potential inhibitors of milk fat
333 synthesis (Bauman & Griinari, 2001; Couvreur et al., 2006). The reduction in milk protein
334 content in summer may be attributed to the decreased propionate production in the rumen as a

335 consequence of the higher forage:concentrate ratio in the diet during the grazing season
336 (Bannink et al., 2006). Milk lactose content in both production systems also dropped when
337 cows were provided with increasing amounts of fresh pasture, whereas the minimal level
338 appeared at late grazing season. The seasonal variation of lactose was greater in the organic
339 than in the conventional production system, which was likely associated with the different
340 dietary starch levels between production systems (Rius et al., 2010), as concentrate intake was
341 kept relatively stable during the year in conventional farms, whereas it decreased to a lower level
342 during the grazing season in organic farms, reaching the minimum in August when the lowest
343 milk lactose content was also observed.

344 *4.2 Milk macromineral and trace element concentrations*

345 *4.2.1 Effects of production system on milk mineral and trace element concentrations*

346 The concentrations of Ca and P were higher in organic milk than conventional milk. Our results
347 disagree with the findings of Poulsen et al. (2015) who compared the mineral compositions of
348 bulk milk from two conventional dairies and one organic dairy in Denmark and reported lower
349 Ca and P concentrations in organic milk. Moreover, a meta-analysis investigating the mineral
350 profile of bovine raw milk based on 72 different studies from 37 countries showed that Ca and
351 P concentrations were lower in organic milk when compared with conventional milk, although
352 differences between countries were acknowledged as well (Zwierzchowski & Ametaj, 2018).
353 Poulsen et al. (2015) suggested a positive correlation between milk P concentration and protein
354 content. However, this explanation is not applicable in the present study as protein contents
355 were generally similar in both conventional and organic milk throughout the year.
356 Milk K concentration was observed higher in organic milk than conventional milk. However,
357 our result is contrary to the finding of the meta-analysis by Zwierzchowski et al. (2018), in
358 which it was reported that conventional milk tended to contain more K than organic milk due

359 to the excessive use of K-rich fertilizer in conventional swards. This may not necessarily be
360 the case in the present study which represented the organic and conventional systems in
361 southern England.

362 The concentrations of Ca and P in milk are relatively constant and are mainly determined by
363 genetics (van Hulzen, Sprong, van der Meer, & van Arendonk, 2009). The contradiction
364 between our results and others' might be explained by differences in breed make-up of the
365 herds, which is supported by the strong positive correlations of Ca, P and K concentrations
366 with alternative (non-Holstein) breeds in the RDA results. Regarding the effects of diet, the
367 RDA results suggested that Ca, P and K concentrations were positively correlated with grazing
368 and total forage intakes, while Ca concentration was also positively correlated with wholecrop,
369 cereals and grass/grass-clover silage intakes. In addition, their concentrations were negatively
370 correlated with intakes of maize silage, dry-straights, minerals, moist by-products and oils.
371 Moreover, a previous finding suggested that maize silage has low Ca and P concentrations and
372 supplementation of these minerals is required when maize silage comprises 25% or more of
373 DMI (Kolver, Roche, Miller, & Densley, 2001). Therefore, the considerably higher proportion
374 of maize silage in conventional diets when compared with organic diets (24.8% DMI vs. 0.9%
375 DMI) could be an important driver of the higher Ca and P concentrations in organic milk. In
376 addition, the higher Ca, P and K concentrations in organic milk may have been partly driven
377 by the numerically higher contribution of grazing, wholecrop, grass/grass-clover silage and
378 cereals to organic diets, as well as the extremely low intakes of dry-straights (<1% DMI), moist
379 by-products (<1% DMI) and oils (non-fed). The fact that Ca and P contents in milk may
380 represent the combined effect of cow diet and breed has been previously reported by
381 Zwierzchowski et al. (2018).

382 Milk concentrations of five essential trace elements, including Cu, Fe, Mn, Mo and Zn, were
383 different between production systems. The average concentrations of Cu, Fe, Mn and Zn during

384 the year were lower in organic milk. These results correspond to the findings of several studies
385 in which the profiles of essential trace elements of conventionally and organically produced
386 milk were compared (Rey-Crespo et al., 2013; Rodriguez-Bermudez et al., 2018;
387 Zwierzchowski et al., 2018). The lower concentrations of these essential trace elements in
388 organic milk may have resulted from the lower concentrate intake in organic herds, because
389 concentrates typically contain higher levels of Co, Cu, I, Se and Zn than forages due to the
390 routine supplementation of these minerals (Orjales et al., 2018). Previous analyses of mineral
391 contents of organic and conventional diets have shown that conventional diets contained higher
392 concentrations of Cu and Zn (Lopez-Alonso et al., 2017; Orjales et al., 2018). The RDA results
393 of the current study provide further evidence on the potential reasons for this observation,
394 showing that concentrations of Cu, Fe, Mn and Zn were mainly driven by intakes of maize
395 silage, dry-straights, moist by products, minerals and oils (all higher in conventional herds) and
396 were negatively correlated with grazing and total forage intakes and the proportion of non-
397 Holstein breed in the herd (all higher in organic herds). Previous findings also highlighted the
398 influence of cow breed on the concentrations of Fe, Mn and Zn in milk (Zwierzchowski et al.,
399 2018).

400 Conversely, the average Mo concentration was higher in organic milk than conventional milk.
401 The higher Mo concentration in organic milk may, again, be associated with higher dietary Mo
402 intake, as a previous study has reported higher Mo concentrations in the diet and blood of
403 organically managed cows when compared with conventionally managed cows (Lopez-Alonso
404 et al., 2017). The RDA results in the present study confirmed the previous findings that both
405 diet and breed may influence milk Mo concentration (Zwierzchowski et al., 2018). The higher
406 Mo content in organic milk may be explained by the higher contribution of alternative (non-
407 Holstein) breeds, higher intakes of wholecrop, grass/grass-clover silage and cereals, and lower
408 intakes of maize silage, dry straights, moist by-products and oils, according to the RDA results.

409 The concentrations of forementioned essential trace elements in milk shared common patterns
410 related to the interaction between production system and month, i.e., similar differences
411 between production systems were observed in specific months. For instance, conventional milk
412 contained higher levels of Cu, Fe, Mn, Mo and Zn in July and August (when differences in
413 grazing intake and forage: concentrate ratio between the systems were maximised), higher
414 levels of Cu, Fe, Mn and Zn in January and March, lower levels of Cu, Mn, Mo and Zn in
415 February and lower levels of Cu, Mo and Zn in September. Given that genetics in the herds
416 were stable throughout the year, these patterns potentially reflect changes in dietary supply of
417 these minerals via various dietary changes.

418 Previous studies have also summarised other potential parameters that influence the
419 concentrations of these minerals, such as water quality and composition, Cu originating from
420 infrastructure, distance from industrial facilities, negative interactions/correlations between
421 minerals (e.g. Cu vs Zn), skimming of milk (Zwierzchowski et al., 2018). However, data in
422 relation to these additional parameters were not available in the present study.

423 The average milk I concentrations were similar between production systems. A decreased I
424 concentration has been commonly observed in organic milk when compared with conventional
425 milk (Bath et al., 2012; Srednicka-Tober et al., 2016; Zwierzchowski et al., 2018). The factors
426 that may decrease I concentration in organic milk have been attributed to less use of iodophor
427 sanitizer, lower intake of mineral-supplemented concentrates and higher intake of goitrogen-
428 enriched forage, which hampers iodine absorption and transfer into the mammary gland and
429 milk (Flachowsky, Franke, Meyer, Leiterer, & Schone, 2014; Rey-Crespo et al., 2013). Despite
430 the absence of a difference in the average concentration, organic milk had a lower I
431 concentration than conventional milk in June and July when the difference in grazing and
432 concentrate intakes was almost maximised between production systems. Therefore, the lower
433 I concentration in organic milk in June and July may have resulted from (i) greater grazing

434 intake, which is known to reduce milk I content (Flachowsky et al., 2014) and also confirmed
435 by their strong negative correlation in the RDA of this study and (ii) potential higher ingestion
436 of clover-containing pastures used in organic farming, which contain greater quantities of
437 goitrogenic compounds than perennial ryegrass pastures used in conventional farming
438 (Flachowsky et al., 2014).

439 Of the determined non-essential trace and toxic heavy metal elements that were accurately
440 quantified in this study, only the average concentration of Al showed a significant effect of
441 production system. The higher content of Al in conventional milk is in line with a previous
442 study which showed that Al concentration in conventional milk was 6.5-fold greater than that
443 in organic milk (Zwierzchowski et al., 2018). Differences in soil acidity and water
444 quality/process may influence Al content in milk (Zwierzchowski et al., 2018) but such records
445 were not available in the present study. In addition, the concentrations of Al and Sn showed
446 similar patterns related to the interaction between production system and month as the
447 forementioned essential trace elements did, as a higher Al concentration was observed in
448 January, March and July, and a higher Sn concentration was observed in January and March in
449 conventional milk. The RDA results indicated that potential drivers for higher milk Al and Sn
450 concentrations can be intakes of maize silage, dry-straights, minerals, moist by-products and
451 oils (used more extensively in conventional farms), while their concentrations were negatively
452 correlated with grazing and total forage intakes as well as the proportion of alternative breeds.
453 The concentration of heavy metal elements in milk largely depends on the environment and the
454 use of fertilizer (Lopez-Alonso, 2012). The difference in the concentrations of As, Cd, Cr and
455 Pb between conventional and organic milk has been reported by others (Rodriguez-Bermudez
456 et al., 2018; Zwierzchowski et al., 2018), although most measured values for these elements
457 were below the quantification limit of analysis in the present study. In general, the present
458 study suggested that concentrations of heavy metal elements were very low in both types of

459 milk and their concentrations were well below the tolerable intake values (Vracko, Tuomisto,
460 Grad, & Kunseler, 2007).

461 *4.2.2 Seasonal variation of milk macromineral and trace element concentrations*

462 The concentrations of all determined minerals varied significantly over time. Although the
463 concentrations of macrominerals showed similar patterns over sequential months, no obvious
464 pattern over seasons was observed. Most determined essential trace elements (except Fe) had
465 a relatively higher concentration in milk between January and March than the rest of the year.
466 Their profiles over months may correspond to the previous finding that milk essential trace
467 element concentrations are generally higher during winter than summer due to higher
468 concentrate intake and lower grazing intake (Rey-Crespo et al., 2013). The RDA results
469 confirmed the previous findings, as grazing intake was identified as the main driver for the
470 concentrations of many milk minerals (except Ca, K, P, Mg and Na, on which the impact is
471 rather low). Milk I concentration showed an obvious decrease with the increase of grazing
472 intake in summer, which is also supported by the negative correlation between them in the
473 RDA. The reduction of milk I concentration during the grazing season has been prevalently
474 reported and has been attributed to decreased I intake and increased goitrogen ingestion
475 (Flachowsky et al., 2014; Pennington, 1990). The seasonal variation of I concentration was
476 more marked in organic milk than conventional milk, in line with the findings of previous
477 works which compared I concentrations in retail milk between summer and winter (Stevenson,
478 Drake, & Givens, 2018; van de Kamp et al., 2019). The greater seasonal variation of I
479 concentration in organic milk may have resulted from the greater change in grazing intake
480 during the year in organic farms when compared with conventional farms.

481 *4.2.3 Potential impact of dairy production system on the mineral intakes of UK consumers*

482 Milk is a major source of various minerals (notably Ca, I, Mg), particularly for age groups that
483 may have increased requirements, such as pregnant women and nursing mothers (Scholz-
484 Ahrens, Ahrens, & Barth, 2020). Given the differences in mineral composition between
485 conventional and organic milk, the choice of consuming one or the other may impact the
486 mineral intake of consumers. To assess the impact of dairy production system on the mineral
487 intakes, the intakes of liquid milk for different age groups in the UK population were calculated
488 from their total energy intakes and the percentages of the energy intake contributed by liquid
489 milk, as recorded by the National Diet and Nutrition Survey (Roberts et al., 2018) and the
490 average milk energy content in liquid milk (Pinchen, Powell, Weiner, & Finglas, 2019). The
491 daily intakes of macrominerals and essential trace elements that had significantly different
492 average concentrations between production systems (Ca, K, P, Cu, Fe, Mn, Mo and Zn) were
493 then calculated based on milk intakes and the quantified concentrations in the present study
494 and were compared with the nutrition recommendations (Roberts et al., 2018).

495 Depending on the intake, milk provides all age groups with an essential part of the reference
496 nutrient intake (RNI) for macrominerals Ca (34%-75%), K (20%-43%) and P (35%-75%). The
497 greatest contribution of milk to Ca, K and P intakes is seen for children 1.5-3 years old whose
498 diet relies more on milk than that of other age groups. Substituting conventional with organic
499 milk in children 1.5-3.0 years old will slightly increase the contribution towards RNIs of Ca
500 (from 70.6% to 74.5%; +13.4 mg/day), K (from 42.3% to 42.9%; +5.3 mg/day) and P (from
501 72.9% to 74.2%; +3.4 mg/day). Similar increased contribution of milk are observed in the other
502 age and gender groups, but given that children 1.5-3.0 years old have the greatest reliance on
503 milk intake as well as the lowest RNIs of minerals among the age groups, the corresponding
504 impact on the other age and gender groups would be at an even lower scale. Although milk is
505 the main supplier of Ca, K and P in human diets and concentrations of these minerals in milk
506 are influenced by dairy production system, it is unlikely that substituting conventional with

507 organic milk would have any effect on human health because of the relatively low impact
508 towards changing the contribution to RNIs.

509 As regards to the essential trace elements which were affected by dairy production system,
510 milk (regardless of production system) provides with a proportion of RNI for Cu (1.6-3.8%),
511 Fe (1.2-7.3%), Mn (0.3-0.9%), Mo (0.04-0.11%) and Zn (10.9-24.8%). Taking as an example
512 of the age group children 1.5-3.0 years old that receives the highest potential impact due to
513 high milk intake and low RNI, substituting conventional with organic milk would reduce the
514 intakes of Cu (from 3.8% to 3.3% RNI; -2.1 µg/day), Fe (from 7.3% to 2.4% RNI; -0.34
515 mg/day), Mn (from 0.9% to 0.6% RNI; -4.0 µg /day) and Zn (from 24.8% to 22.4% RNI; -0.12
516 mg/day) and increase the intake of Mo (from 0.09% to 0.11% RNI; +3.16 µg/day). Similar to
517 the macrominerals, differences in intakes of essential trace elements from milk appear to be
518 too small to impact human health.

519 Iodine concentration of organic milk has often been reported to be lower than that of
520 conventional milk and previous studies highlighted that certain consumer groups of organic
521 milk with high I requirements (e.g. nursing mothers and pregnant women) may need to
522 consume higher quantities of milk or alternative food sources of iodine to meet their nutritional
523 requirements (Bath et al., 2012; Stevenson et al., 2018). In this study, although there was no
524 significant overall difference in I content between the two types of milk, organic milk contained
525 less I than conventional milk during two months of the grazing season (278 µg/kg vs. 316 µg/kg
526 in June; 248 µg/kg vs. 269 µg/kg in July). For children 1.5-3.0 years old, switching from
527 conventional milk to organic milk would reduce I intake from 108.8% to 95.6% RNI (-9.3
528 µg/day). In case of pregnant women and nursing mothers, for whom RNI of I is 250 µg/d
529 (Andersson, de Benoist, Delange, Zupan, & Secretariat, 2007), assuming average milk intake
530 similar to women 19-65 years old, consuming organic milk would reduce I intake from 30.5%
531 to 26.8% RNI (-13.2 µg/day). The potential impact on nutrition is therefore lower than reported

532 in other studies (Bath et al., 2012; Stevenson et al., 2018). This is possibly because the
533 conventional systems in the present study also allowed their cows to graze in summer
534 (supplementary Figure S1). This may have reduced the difference in pasture intakes between
535 the two production systems, subsequently reducing the potential difference in I intakes based
536 on organic or conventional milk because pasture intake was seen as a major driver for milk I
537 content in the RDA. Notably, I contents in conventional and organic milk were decreased, e.g.
538 from 426 µg/kg and 485 µg/kg in March to 269 µg/kg and 248 µg/kg in July, respectively. The
539 variation over months may have a greater impact on consumers' I intake than dairy production
540 system does.

541 **5. Conclusions**

542 The organic farms in the present study had lower average daily milk yield per cow and milk
543 lactose content when compared with the conventional farms, while milk fat and protein
544 contents during late summer were higher in organic milk than in conventional milk. Across
545 production systems, milk protein, fat, lactose contents were lower during the grazing season.
546 Organic milk contained higher levels of macrominerals Ca, K, P when compared with
547 conventional milk. In contrast, with respect to essential trace elements, organic milk contained
548 on average less Cu, Fe, Mn and Zn but more Mo than conventional milk. Milk I concentration
549 was lower in organic milk in June and July when compared with conventional milk. The
550 concentrations of all determined elements varied significantly over months with higher
551 concentrations of Cu, I, Mn, Mo and Zn observed between January and March compared with
552 the other months. Differences in milk mineral concentrations between organic and
553 conventional systems may be explained by the different dietary ingredients making up
554 conventional and organic dairy cow diets, including intakes of maize silage, moist-by products,
555 dry-straights, minerals and oils (higher in conventional cow diets) and intakes of total forage,
556 pasture, grass/grass-clover silage and wholecrop (higher in organic farms). In addition, the

557 multivariate redundancy analysis suggested a secondary effect of cow breed, in particular the
558 higher contribution of alternative breeds and crossbreeds in organic herds in expense of
559 Holstein. The magnitude of the differences in milk mineral composition appeared to have a
560 rather small impact on the expected contribution of milk to the reference nutrient intakes,
561 according to recorded milk intakes of the UK population. Therefore, the differences in milk
562 mineral composition are likely not large enough to have any meaningful impact on human
563 health.

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574 **References**

- 575 Andersson, M., de Benoist, B., Delange, F., Zupan, J., & Secretariat, W. (2007). Prevention
576 and control of iodine deficiency in pregnant and lactating women and in children less
577 than 2-years-old: conclusions and recommendations of the Technical Consultation.
578 *Public Health Nutrition*, *10*(12a), 1606-1611.
579 <https://doi.org/10.1017/S1368980007361004>.
- 580 Bannink, A., Kogut, J., Dijkstra, J., France, J., Kebreab, E., Van Vuuren, A. M., & Tamminga,
581 S. (2006). Estimation of the stoichiometry of volatile fatty acid production in the rumen
582 of lactating cows. *Journal of Theoretical Biology*, *238*(1), 36-51.
583 <https://doi.org/10.1016/j.jtbi.2005.05.026>.
- 584 Bath, S. C., Button, S., & Rayman, M. P. (2012). Iodine concentration of organic and
585 conventional milk: implications for iodine intake. *British Journal of Nutrition*, *107*(7),
586 935-940. <https://doi.org/10.1017/S0007114511003059>.

- 587 Bauman, D. E., & Griinari, J. M. (2001). Regulation and nutritional manipulation of milk fat:
588 low-fat milk syndrome. *Livestock Production Science*, 70(1-2), 15-29. <Go to
589 ISI>://WOS:000169719400003.
- 590 Bernabucci, U., Basirico, L., Morera, P., Dipasquale, D., Vitali, A., Cappelli, F. P., & Calamari,
591 L. (2015). Effect of summer season on milk protein fractions in Holstein cows. *Journal*
592 *of Dairy Science*, 98(3), 1815-1827. <https://doi.org/10.3168/jds.2014-8788>.
- 593 Butler, G., Nielsen, J. H., Slots, T., Seal, C., Eyre, M. D., Sanderson, R., & Leifert, C. (2008).
594 Fatty acid and fat-soluble antioxidant concentrations in milk from high- and low-input
595 conventional and organic systems: seasonal variation. *Journal of the Science of Food*
596 *and Agriculture*, 88(8), 1431-1441. <https://doi.org/10.1002/jsfa.3235>.
- 597 Couvreur, S., Hurtaud, C., Lopez, C., Delaby, L., & Peyraud, J. L. (2006). The linear
598 relationship between the proportion of fresh grass in the cow diet, milk fatty acid
599 composition, and butter properties. *Journal of Dairy Science*, 89(6), 1956-1969.
600 [https://doi.org/DOI 10.3168/jds.S0022-0302\(06\)72263-9](https://doi.org/DOI%2010.3168/jds.S0022-0302(06)72263-9).
- 601 Flachowsky, G., Franke, K., Meyer, U., Leiterer, M., & Schone, F. (2014). Influencing factors
602 on iodine content of cow milk. *European Journal of Nutrition*, 53(2), 351-365.
603 <https://doi.org/10.1007/s00394-013-0597-4>.
- 604 Heck, J. M. L., van Valenberg, H. J. F., Dijkstra, J., & van Hooijdonk, A. C. M. (2009).
605 Seasonal variation in the Dutch bovine raw milk composition. *Journal of Dairy Science*,
606 92(10), 4745-4755. <https://doi.org/10.3168/jds.2009-2146>.
- 607 Kolver, E., Roche, J., Miller, D., & Densley, R. (2001). Maize silage for dairy cows.
608 *Proceedings of the New Zealand Grasslands Association*, 63.
609 <https://doi.org/10.33584/jnzc.2001.63.2407>.
- 610 Lopez-Alonso, M. (2012). Animal feed contamination by toxic metals. *Animal Feed*
611 *Contamination: Effects on Livestock and Food Safety*(215), 183-204.
612 [https://doi.org/Book_Do 10.1533/9780857093615](https://doi.org/Book_Do%2010.1533/9780857093615).
- 613 Lopez-Alonso, M., Rey-Crespo, F., Herrero-Latorre, C., & Miranda, M. (2017). Identifying
614 sources of metal exposure in organic and conventional dairy farming. *Chemosphere*,
615 185, 1048-1055. <https://doi.org/10.1016/j.chemosphere.2017.07.112>.
- 616 Miller, R., Spiro, A., & Stanner, S. (2016). Micronutrient status and intake in the UK - where
617 might we be in 10 years' time? *Nutrition Bulletin*, 41(1), 14-41.
618 <https://doi.org/10.1111/nbu.12187>.
- 619 NMKL 186, N. (2007). Trace elements - As, Cd, Hg, Pb and other elements. Determination by
620 ICP-MS after pressure digestion. Retrieved from:
621 [https://www.nmkl.org/index.php/en/publications/item/tungmetaller-as-cd-hg-og-pb-](https://www.nmkl.org/index.php/en/publications/item/tungmetaller-as-cd-hg-og-pb-bestemmelse-med-icp-ms-etter-syreoppslutning-under-trykk-nmkl-186-2007)
622 [bestemmelse-med-icp-ms-etter-syreoppslutning-under-trykk-nmkl-186-2007](https://www.nmkl.org/index.php/en/publications/item/tungmetaller-as-cd-hg-og-pb-bestemmelse-med-icp-ms-etter-syreoppslutning-under-trykk-nmkl-186-2007)
623 Accessed 10 August 2020.
- 624 O'Brien, B., Lennartsson, T., Mehra, R., Cogan, T. M., Connolly, J. F., Morrissey, P. A., &
625 Harrington, D. (1999). Seasonal variation in the composition of Irish manufacturing
626 and retail milks - 3. Vitamins. *Irish Journal of Agricultural and Food Research*, 38(1),
627 75-85. <Go to ISI>://WOS:000081234000007.
- 628 Orjales, I., Herrero-Latorre, C., Miranda, M., Rey-Crespo, F., Rodriguez-Bermudez, R., &
629 Lopez-Alonso, M. (2018). Evaluation of trace element status of organic dairy cattle.
630 *Animal*, 12(6), 1296-1305. <https://doi.org/10.1017/S1751731117002890>.
- 631 Palladino, R. A., Buckley, F., Prendiville, R., Murphy, J. J., Callan, J., & Kenny, D. A. (2010).
632 A comparison between Holstein-Friesian and Jersey dairy cows and their F-1 hybrid on
633 milk fatty acid composition under grazing conditions. *Journal of Dairy Science*, 93(5),
634 2176-2184. <https://doi.org/10.3168/jds.2009-2453>.
- 635 Payling, L. M., Juniper, D. T., Drake, C., Rymer, C., & Givens, D. I. (2015). Effect of milk
636 type and processing on iodine concentration of organic and conventional winter milk at

- 637 retail: Implications for nutrition. *Food Chemistry*, 178, 327-330.
638 <https://doi.org/10.1016/j.foodchem.2015.01.091>.
- 639 Pennington, J. A. T. (1990). Iodine Concentrations in United-States Milk - Variation Due to
640 Time, Season, and Region. *Journal of Dairy Science*, 73(12), 3421-3427.
641 [https://doi.org/DOI 10.3168/jds.S0022-0302\(90\)79039-X](https://doi.org/DOI%2010.3168/jds.S0022-0302(90)79039-X).
- 642 Pinchen, H., Powell, N., Weiner, D., & Finglas, P. (2019). McCance and Widdowson's The
643 Composition of Foods Integrated Dataset. Retrieved from:
644 [https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachme
645 nt_data/file/788485/McCance_Widdowson_Comp_Foods_Integrated_Dataset_User_
646 Guide_2019__1_.pdf](https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/788485/McCance_Widdowson_Comp_Foods_Integrated_Dataset_User_Guide_2019__1_.pdf) Accessed 10 August 2020.
- 647 Poulsen, N. A., Rybicka, I., Poulsen, H. D., Larsen, L. B., Andersen, K. K., & Larsen, M. K.
648 (2015). Seasonal variation in content of riboflavin and major minerals in bulk milk from
649 three Danish dairies. *International Dairy Journal*, 42, 6-11.
650 <https://doi.org/10.1016/j.idairyj.2014.10.010>.
- 651 Rey-Crespo, F., Miranda, M., & Lopez-Alonso, M. (2013). Essential trace and toxic element
652 concentrations in organic and conventional milk in NW Spain. *Food and Chemical*
653 *Toxicology*, 55, 513-518. <https://doi.org/10.1016/j.fct.2013.01.040>.
- 654 Rius, A. G., Appuhamy, J. A. D. R. N., Cyriac, J., Kirovski, D., Becvar, O., Escobar, J., . . .
655 Hanigan, M. D. (2010). Regulation of protein synthesis in mammary glands of lactating
656 dairy cows by starch and amino acids. *Journal of Dairy Science*, 93(7), 3114-3127.
657 <https://doi.org/10.3168/jds.2009-2743>.
- 658 Roberts, C., Steer, T., Maplethorpe, N., Cox, L., Meadows, S., Nicholson, S., Page, P., & Swan,
659 G. (2018). National Diet and Nutrition Survey. Results from Years 7-8 (combined) of
660 the Rolling Programme (2014/15 to 2015/16): A survey carried out on behalf of Public
661 Health England and the Food Standards Agency. Retrieved from:
662 [https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachme
663 nt_data/file/699241/NDNS_results_years_7_and_8.pdf/](https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/699241/NDNS_results_years_7_and_8.pdf/) Accessed 10 August 2020.
- 664 Rodriguez-Bermudez, R., Lopez-Alonso, M., Miranda, M., Fouz, R., Orjales, I., & Herrero-
665 Latorre, C. (2018). Chemometric authentication of the organic status of milk on the
666 basis of trace element content. *Food Chemistry*, 240, 686-693.
667 <https://doi.org/10.1016/j.foodchem.2017.08.011>.
- 668 Scholz-Ahrens, K. E., Ahrens, F., & Barth, C. A. (2020). Nutritional and health attributes of
669 milk and milk imitations. *European Journal of Nutrition*, 59(1), 19-34.
670 <https://doi.org/10.1007/s00394-019-01936-3>.
- 671 Schwendel, B. H., Wester, T. J., Morel, P. C. H., Tavendale, M. H., Deadman, C., Shadbolt,
672 N. M., & Otter, D. E. (2015). Invited review: Organic and conventionally produced
673 milk-An evaluation of influence factors on milk composition (vol 98, pg 721, 2015).
674 *Journal of Dairy Science*, 98(4), 2831-2831. [https://doi.org/10.3168/jds.2015-98-4-
675 2831](https://doi.org/10.3168/jds.2015-98-4-2831).
- 676 Srednicka-Tober, D., Baranski, M., Seal, C. J., Sanderson, R., Benbrook, C., Steinshamn, H., .
677 . . . Leifert, C. (2016). Higher PUFA and n-3 PUFA, conjugated linoleic acid, alpha-
678 tocopherol and iron, but lower iodine and selenium concentrations in organic milk: a
679 systematic literature review and meta- and redundancy analyses. *British Journal of*
680 *Nutrition*, 115(6), 1043-1060. <https://doi.org/10.1017/S0007114516000349>.
- 681 Stergiadis, S., Bieber, A., Chatzidimitriou, E., Franceschin, E., Isensee, A., Rempelos, L., . . .
682 Leifert, C. (2018). Impact of US Brown Swiss genetics on milk quality from low-input
683 herds in Switzerland: Interactions with season. *Food Chemistry*, 251, 93-102.
684 <https://doi.org/10.1016/j.foodchem.2018.01.077>.
- 685 Stergiadis, S., Leifert, C., Seal, C. J., Eyre, M. D., Larsen, M. K., Slots, T., . . . Butler, G.
686 (2015). A 2-year study on milk quality from three pasture-based dairy systems of

687 contrasting production intensities in Wales. *Journal of Agricultural Science*, 153(4),
688 708-731. <https://doi.org/10.1017/S0021859614000963>.

689 Stergiadis, S., Leifert, C., Seal, C. J., Eyre, M. D., Nielsen, J. H., Larsen, M. K., . . . Butler, G.
690 (2012). Effect of Feeding Intensity and Milking System on Nutritionally Relevant Milk
691 Components in Dairy Farming Systems in the North East of England. *Journal of*
692 *Agricultural and Food Chemistry*, 60(29), 7270-7281.
693 <https://doi.org/10.1021/jf301053b>.

694 Stevenson, M. C., Drake, C., & Givens, D. I. (2018). Further studies on the iodine concentration
695 of conventional, organic and UHT semi-skimmed milk at retail in the UK. *Food*
696 *Chemistry*, 239, 551-555. <https://doi.org/10.1016/j.foodchem.2017.06.135>.

697 Sundberg, T., Berglund, B., Rydhmer, L., & Strandberg, E. (2009). Fertility, somatic cell count
698 and milk production in Swedish organic and conventional dairy herds. *Livestock*
699 *Science*, 126(1-3), 176-182. <https://doi.org/10.1016/j.livsci.2009.06.022>.

700 Tunick, M. H., Van Hekken, D. L., Paul, M., Ingham, E. R., & Karreman, H. J. (2016). Case
701 study: Comparison of milk composition from adjacent organic and conventional farms
702 in the USA. *International Journal of Dairy Technology*, 69(1), 137-142.
703 <https://doi.org/10.1111/1471-0307.12284>.

704 Valle, P. S., Lien, G., Flaten, O., Koesling, M., & Ebbesvik, M. (2007). Herd health and health
705 management in organic versus conventional dairy herds in Norway. *Livestock Science*,
706 112(1-2), 123-132. <https://doi.org/10.1016/j.livsci.2007.02.005>.

707 van de Kamp, M. E., Saridakis, I., & Verkaik-Kloosterman, J. (2019). Iodine content of semi-
708 skimmed milk available in the Netherlands depending on farming (organic versus
709 conventional) and heat treatment (pasteurized versus UHT) and implications for the
710 consumer. *Journal of Trace Elements in Medicine and Biology*, 56, 178-183.
711 <https://doi.org/10.1016/j.jtemb.2019.08.008>.

712 van Hulzen, K. J. E., Sprong, R. C., van der Meer, R., & van Arendonk, J. A. M. (2009). Genetic
713 and nongenetic variation in concentration of selenium, calcium, potassium, zinc,
714 magnesium, and phosphorus in milk of Dutch Holstein-Friesian cows. *Journal of Dairy*
715 *Science*, 92(11), 5754-5759. <https://doi.org/10.3168/jds.2009-2406>.

716 Vracko, P., Tuomisto, J., Grad, J., & Kunseler E. (2007). Exposure of children to chemical
717 hazards in food Retrieved from:
718 https://www.euro.who.int/__data/assets/pdf_file/0003/97446/4.4.pdf Accessed 01
719 October 2020.

720 Weller, R. F., & Bowling, P. J. (2007). The importance of nutrient balance, cropping strategy
721 and quality of dairy cow diets in sustainable organic systems. *Journal of the Science of*
722 *Food and Agriculture*, 87(15), 2768-2773. <https://doi.org/10.1002/jsfa.3001>.

723 Zwierzchowski, G., & Ametaj, B. N. (2018). Minerals and Heavy Metals in the Whole Raw
724 Milk of Dairy Cows from Different Management Systems and Countries of Origin: A
725 Meta-Analytical Study. *Journal of Agricultural and Food Chemistry*, 66(26), 6877-
726 6888. <https://doi.org/10.1021/acs.jafc.8b00904>.

727

Table 1. Herd composition and feed intake in conventional and organic farms.

Parameters assessed	Mean ¹		SE	<i>p</i> -value
	Conventional n = 490	Organic n = 319		
Herd composition (% herd)				
Holstein	78.9	64.2	6.64	0.125
British Friesian	4.5	2.3	2.33	0.510
Ayrshire	2.5	7.8	3.46	0.279
New Zealand Friesian	0.4	1.3	0.75	0.421
Jersey	0.3	2.1	0.83	0.129
Scandinavian Red	0.1	0.9	0.22	0.019
Shorthorn	0	0.7	0.15	0.002
Montbeliarde	0.1	0.1	0.05	0.905
Brown Swiss	0.3	1.8	0.84	0.212
Guernsey	0.1	0	0.03	0.285
Other breed/crossbreed	12.3	18.8	5.81	0.435
Feed intake and composition (% dry matter intake unless otherwise stated)				
Dry matter intake (kg/cow/d)	20.0	18.6	0.27	<0.001
Total forage	61.0	74.3	1.22	<0.001
Total concentrate	39.0	25.7	1.22	<0.001
Grazing intake	8.3	25.4	1.86	<0.001
Grass/grass-clover silage ²	24.4	35.1	1.63	<0.001
Maize silage	24.8	0.9	1.44	<0.001
Lucerne silage	0.4	0.1	0.20	0.307
Other mixed silage	0.3	2.6	0.45	<0.001
Wholecrop silage	0.4	8.0	0.57	<0.001
Hay and straw	2.5	2.2	0.39	0.631
Moist by-product	4.8	0.4	0.77	<0.001
Dry-straight	10.0	0.9	1.62	<0.001
Cereal	2.4	4.0	0.64	0.073
Blend	20.9	20.4	1.92	0.874
Oil	0.8	0	0.11	<0.001
Mineral (g/cow/d)	131.1	68.8	15.64	0.007
Vitamin (g/cow/d)	10.3	0	5.81	0.215

729 ¹Predicted means from the fitted mixed linear model.

730 ²In the conventional production system, this was predominantly perennial ryegrass silage,
731 while in organic systems silage typically has variant grass: clover ratios.

732

733 Table 2. Milk yield, basic composition and macromineral and trace element concentrations in
 734 conventional and organic farms

Parameters assessed	Mean ¹		SE	<i>p</i> -value ²
	Conventional n = 484	Organic n = 316		
Yield and basic composition				
Milk yield (kg/cow/d)	29.5	22.2	0.67	<0.001
Fat (g/kg milk)	39.2	39.8	0.30	0.193
Protein (g/kg milk)	33.4	33.3	0.21	0.560
Lactose (g/kg milk)	45.2	44.8	0.09	0.009
SCC (× 1000/ml milk)	149.9	136.0	2.91	0.102
Macrominerals (mg/kg milk)				
Ca	995.8	1049.5	5.06	<0.001
K	1362.4	1383.6	7.03	0.048
Mg	95.7	95.0	0.53	0.457
Na	343.5	344.7	2.86	0.906
P	792.5	806.5	4.45	0.042
Essential trace elements (µg/kg milk unless otherwise stated)				
Cu	60.6	52.4	1.84	<0.001
Fe (mg/kg milk)	2.03	0.66	0.222	<0.001
I	331.2	364.1	15.99	0.547
Mn	45.0	28.8	2.57	<0.001
Mo	60.6	73.3	1.72	<0.001
Zn (mg/kg milk)	5.00	4.51	0.114	<0.001
Non-essential trace elements				
Al (mg/kg milk)	1.14	0.32	0.120	<0.001
Sn (µg/kg milk)	2.66	2.68	0.300	0.166

735 ¹The means of milk yield, fat, protein and lactose contents are the predicted means obtained
 736 from the fitted mixed linear model. The means of somatic cell count (SCC), macrominerals
 737 and trace elements are the arithmetic means of the measured values.

738 ²The *p*-value of SCC was obtained from the fitted mixed linear model based on log(*x*)-
 739 transformed values. The *p*-values of macrominerals and trace elements were obtained from the
 740 fitted mixed linear model based on the log(*x*+1)-transformed values.

Table 3. Changes of average milk yield, basic composition and macromineral and trace element concentrations of all farms over time.

Parameter	Mean ¹												SE	p-value ²
	Jan n = 67	Feb n = 69	Mar n = 68	Apr n = 68	May n = 68	Jun n = 68	Jul n = 68	Aug n = 67	Sep n = 67	Oct n = 67	Nov n = 67	Dec n = 65		
Yield and basic composition														
Milk yield (kg/cow/d)	26.0 ^{cd}	25.7 ^{cd}	25.8 ^{cd}	26.9 ^{ab}	27.1 ^a	26.1 ^{bc}	25.8 ^{cd}	25.3 ^{cd}	25.2 ^{cd}	25.1 ^d	25.3 ^{cd}	25.9 ^{cd}	0.57	<0.001
Fat (g/kg milk)	40.6 ^{bc}	39.5 ^d	39.7 ^d	38.6 ^e	37.7 ^f	38.3 ^{ef}	36.8 ^g	39.5 ^d	40.3 ^{cd}	41.1 ^{ab}	41.7 ^a	40.8 ^{bc}	0.34	<0.001
Protein (g/kg milk)	33.3 ^c	33.2 ^{cd}	32.8 ^e	33.1 ^{cde}	32.9 ^{de}	32.8 ^{ef}	32.4 ^f	33.2 ^{cd}	33.5 ^c	34.1 ^b	34.7 ^a	34.1 ^b	0.20	<0.001
Lactose (g/kg milk)	45.3 ^b	45.2 ^{bc}	45.5 ^a	45.3 ^b	45.2 ^{bc}	45.0 ^{cd}	44.8 ^e	44.5 ^f	44.6 ^f	44.8 ^e	45.0 ^{de}	45.0 ^{de}	0.09	<0.001
SCC (×1000/ml milk)	147.6 ^{bcd}	127.7 ^{ef}	155.6 ^{abc}	150.6 ^{abcd}	141.3 ^{cde}	164.9 ^a	148.1 ^{abcd}	159.7 ^{ab}	114.4 ^f	142.9 ^{cde}	142.4 ^{cde}	137.7 ^{de}	6.61	<0.001
Macrominerals (mg/kg milk)														
Ca	960.3 ^e	983.1 ^{cde}	1061.2 ^b	976.3 ^{de}	986.7 ^{cd}	925.9 ^f	1058.8 ^b	1006.3 ^c	1069.3 ^b	1094.2 ^a	1039.8 ^b	1042.0 ^b	10.56	<0.001
K	1217.4 ⁱ	1328.9 ^g	1401.4 ^{cde}	1345.8 ^{fg}	1375.1 ^{ef}	1256.3 ^h	1463.0 ^{ab}	1378.4 ^{def}	1435.2 ^{bc}	1468.0 ^a	1363.2 ^{ef}	1417.4 ^{cd}	13.41	<0.001
Mg	88.0 ^f	91.2 ^{de}	100.9 ^b	90.2 ^{ef}	93.5 ^{cd}	85.3 ^g	99.1 ^b	95.1 ^c	101.4 ^b	104.7 ^a	102.1 ^{ab}	93.9 ^{cd}	1.02	<0.001
Na	275.2 ^h	318.0 ^g	380.6 ^b	354.9 ^{cd}	330.2 ^f	309.7 ^g	410.2 ^a	336.2 ^{ef}	353.2 ^d	364.3 ^c	348.1 ^{de}	348.1 ^{de}	5.26	<0.001
P	668.8 ^h	778.6 ^f	842.6 ^{abc}	812.8 ^d	820.7 ^{bcd}	732.5 ^g	841.6 ^{ab}	783.7 ^{ef}	813.4 ^{de}	819.8 ^{cd}	803.0 ^{de}	860.5 ^a	8.33	<0.001
Essential trace elements (µg/kg milk unless otherwise stated)														
Cu	67.8 ^{cd}	71.3 ^b	112.1 ^a	50.3 ^{ef}	42.0 ^{hi}	40.3 ⁱ	56.6 ^{efgh}	65.0 ^c	41.8 ^{ghi}	44.0 ^{fg}	50.9 ^{de}	46.6 ^{efg}	3.23	<0.001
Fe (mg/kg milk)	4.77 ^a	0.86 ^c	2.14 ^{bc}	0.42 ^{ef}	0.21 ^f	0.26 ^{ef}	6.34 ^{ab}	1.27 ^{cd}	0.30 ^{ef}	0.25 ^{ef}	0.75 ^{de}	0.33 ^{ef}	0.371	<0.001
I	426.2 ^a	382.8 ^{ab}	449.7 ^a	338.8 ^{de}	270.6 ^{fg}	300.8 ^{ef}	260.9 ^g	297.8 ^{ef}	334.0 ^{cd}	396.2 ^{ab}	349.8 ^{bc}	323.1 ^{cd}	35.46	<0.001
Mn	77.9 ^b	44.2 ^{bc}	80.2 ^a	24.4 ^e	18.9 ^f	19.8 ^{ef}	73.2 ^{cd}	42.5 ^d	20.3 ^{ef}	19.0 ^f	22.9 ^{ef}	19.5 ^{ef}	4.85	<0.001
Mo	63.3 ^{cd}	82.3 ^b	105.7 ^a	57.3 ^{cd}	54.3 ^d	53.3 ^d	60.7 ^d	79.7 ^b	52.7 ^d	55.9 ^d	64.0 ^c	58.4 ^{cd}	3.18	<0.001
Zn (mg/kg milk)	4.98 ^d	5.86 ^b	8.21 ^a	4.12 ^{def}	3.72 ^g	4.36 ^d	4.88 ^{de}	5.84 ^c	3.91 ^{defg}	3.79 ^{fg}	4.16 ^{def}	3.86 ^{efg}	0.192	<0.001
Non-essential trace elements														
Al (mg/kg milk)	2.92 ^a	0.52 ^{cd}	2.42 ^b	0.26 ^{ef}	0.06 ^f	0.09 ^f	2.24 ^{bc}	0.50 ^{de}	0.18 ^{ef}	0.13 ^{ef}	0.31 ^{def}	0.13 ^{ef}	0.234	<0.001
Sn (µg/kg milk)	3.37 ^{bcd}	2.24 ^{bcd}	4.18 ^a	2.08 ^{cde}	2.96 ^{bc}	1.54 ^{ef}	3.87 ^{ef}	2.28 ^{cde}	1.81 ^f	1.72 ^{ef}	1.67 ^{de}	4.33 ^{abc}	0.532	<0.001

¹The means of milk yield, fat, protein and lactose contents are the predicted means obtained from the fitted mixed linear model. The means of somatic cell count (SCC), macrominerals and trace elements are the arithmetic means of the measured values.

744 ²The *p*-value of SCC was obtained from the fitted mixed linear model based on log(*x*)-transformed values. The *p*-values of macrominerals and trace elements
745 were obtained from the fitted mixed linear model based on the log(*x*+1)-transformed values. Different letters indicate significant (*p* < 0.05) difference between
746 months.

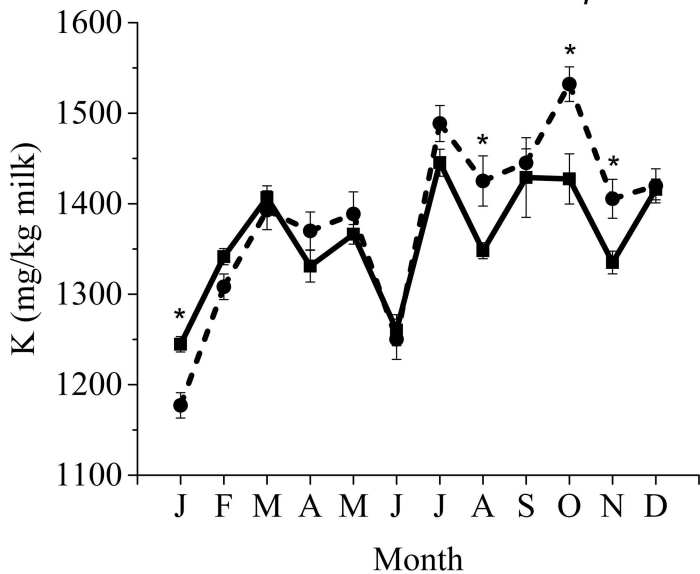
747

748 **Figure 1.** Concentrations of macrominerals (K, P) and non-essential trace elements (Al, Sn) in
749 milk where a significant ($p < 0.05$) interaction between production system and month was
750 observed. Means were calculated from the measured values. The error bars represent the
751 standard error of the means. The p -values were obtained from the fitted mixed linear model
752 based on the $\log(x+1)$ -transformed values. *: significant difference between conventional and
753 organic farms within the month ($p < 0.05$).

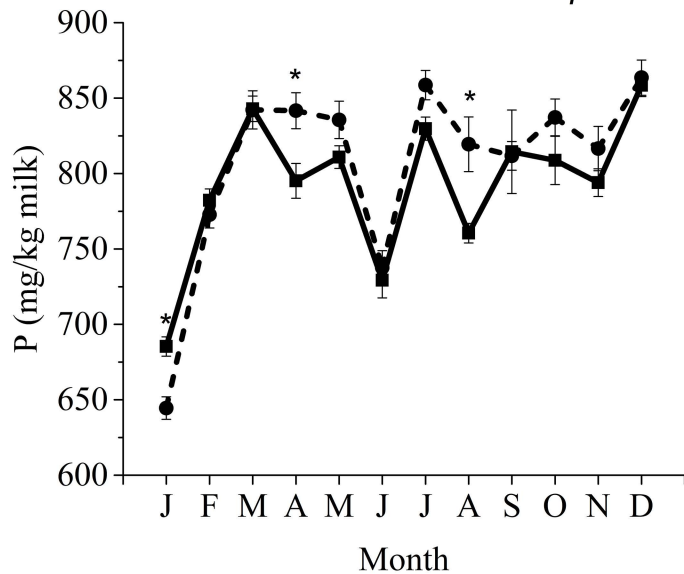
754 **Figure 2.** Concentrations of essential trace elements in milk where a significant ($p < 0.05$)
755 interaction between production system and month was observed. Means were calculated from
756 the measured values. The error bars represent the standard error of the means. The p -values
757 were obtained from the fitted mixed linear model based on the $\log(x+1)$ -transformed values. *:
758 significant difference between conventional and organic farms within the month ($p < 0.05$).

760 **Figure 3.** Biplot derived from the redundancy analysis using our database, showing the
761 relationship between herd breeding (Non-Holstein, NHOL) and diet composition (total forage,
762 TFOR; estimated grazing, GRA; grass and grass/clover silage, GGCS; maize silage, MS;
763 lucerne silage, LS; wholecrop (ensiled whole wheat plants, harvested approximately 1 month
764 before grain maturity), WC; hay/straw, HS; moist by-products, MBP; dry straights, DRY;
765 cereals, CER; oil, OIL; minerals, MIN; and vitamins, VIT) parameters relative to the (i) milk
766 yield (*yield*), milk contents of fat (*fat*), protein (*prot*), lactose (*lact*), somatic cell count (*scc*)
767 and milk concentrations of *Al, Mn, Fe, Cu, Zn, Mo, Sn, Na, Mg, P, K, Ca* and *I*. Axis 1 explained
768 4.2% of the variation and axis 2 a further 2.1%. Continuous variables, shown as arrows were
769 (in order of contribution to the explained variation GRA ($p = 0.002$), MS ($p = 0.002$), TFOR
770 ($p = 0.002$), NHOL ($p = 0.006$), CER ($p = 0.016$), DRY ($p = 0.048$), OIL ($p = 0.046$), MIN (p
771 $= 0.074$), WC ($p = 0.096$), VIT ($p = 0.204$), HS ($p = 0.148$), GGCS ($p = 0.540$), MBP ($p =$
772 0.724), LS ($p = 0.872$).

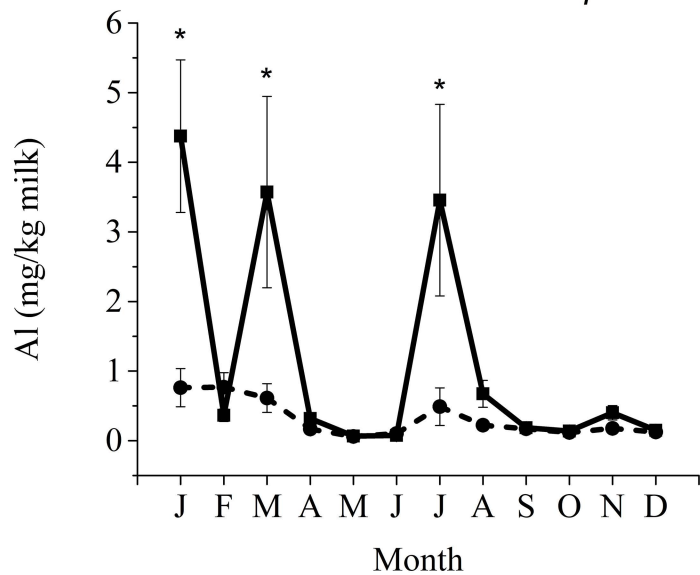
$p < 0.001$



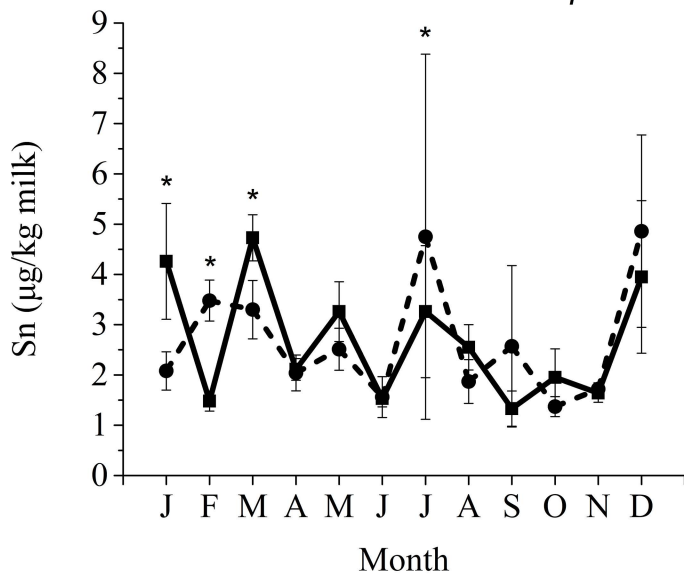
$p < 0.001$



$p < 0.001$

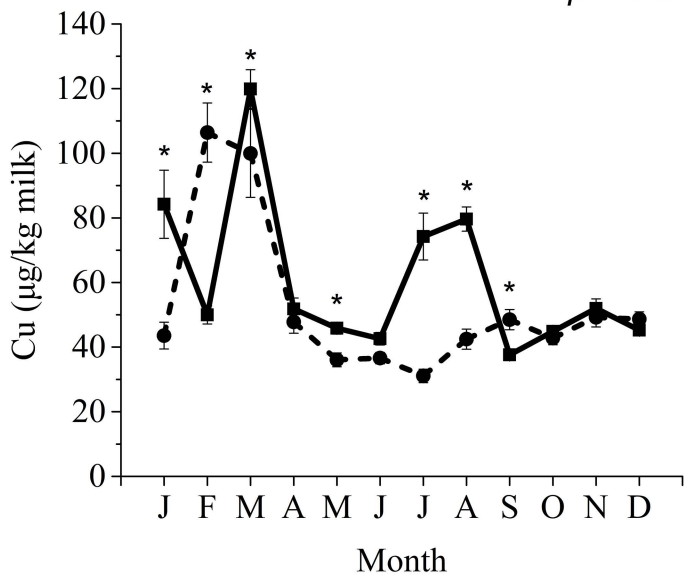


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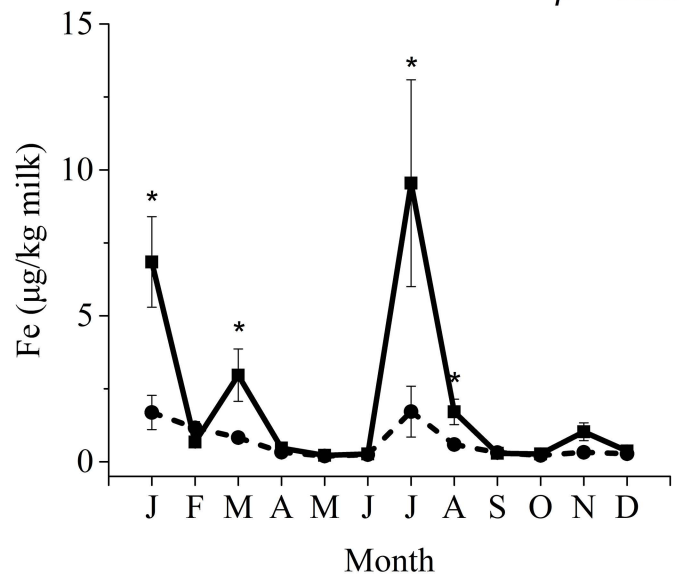


—■— Conventional - -●- - Organic

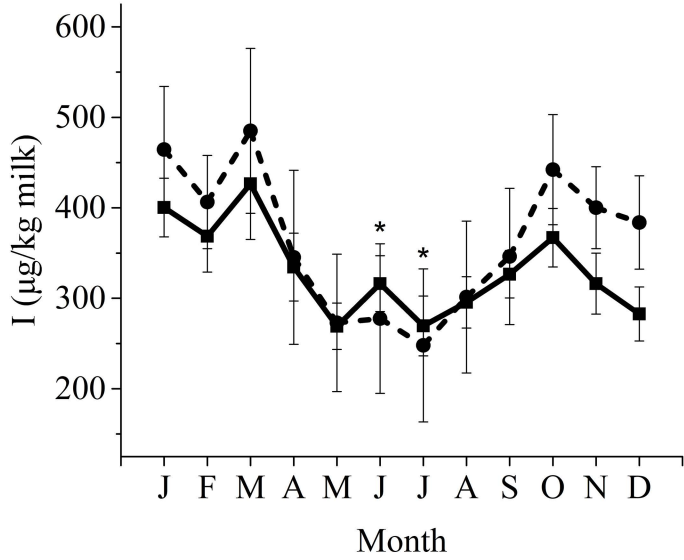
$p < 0.001$



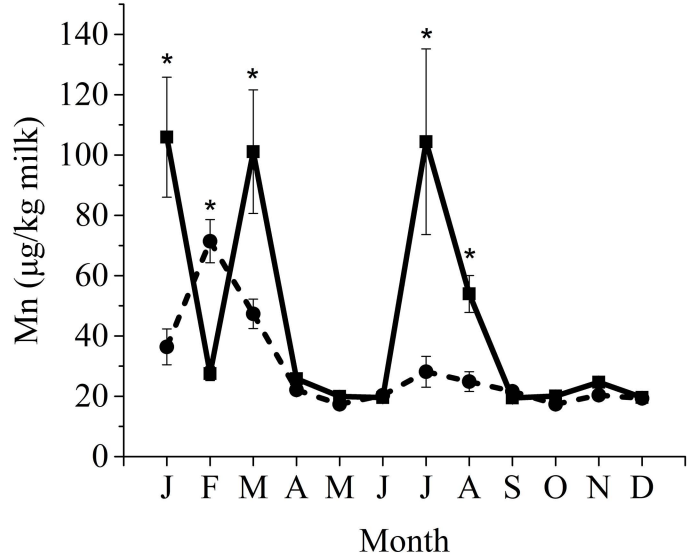
$p < 0.001$



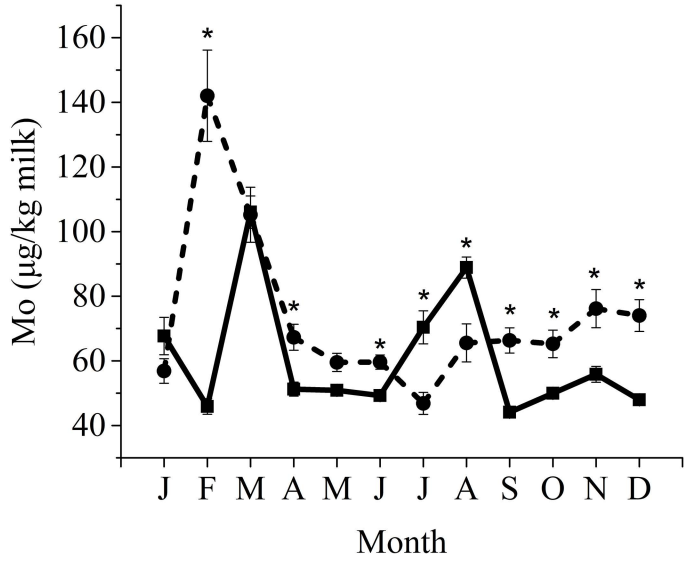
$p < 0.001$



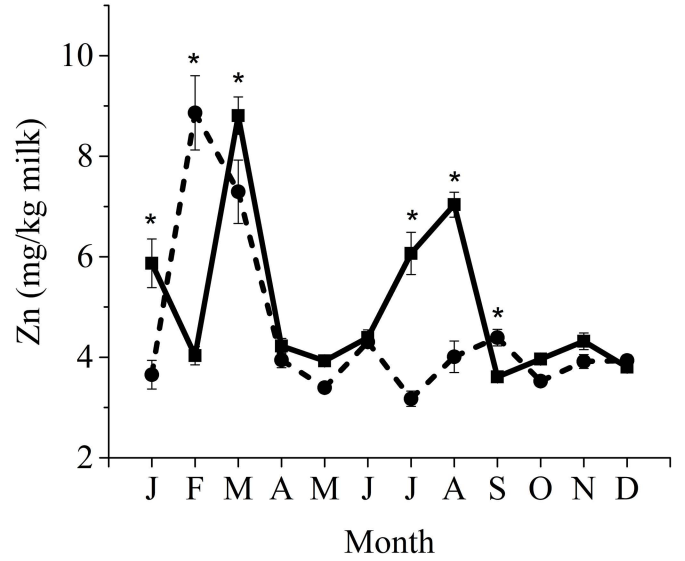
$p < 0.001$



$p < 0.001$



$p < 0.001$



—■— Conventional -●- Organic

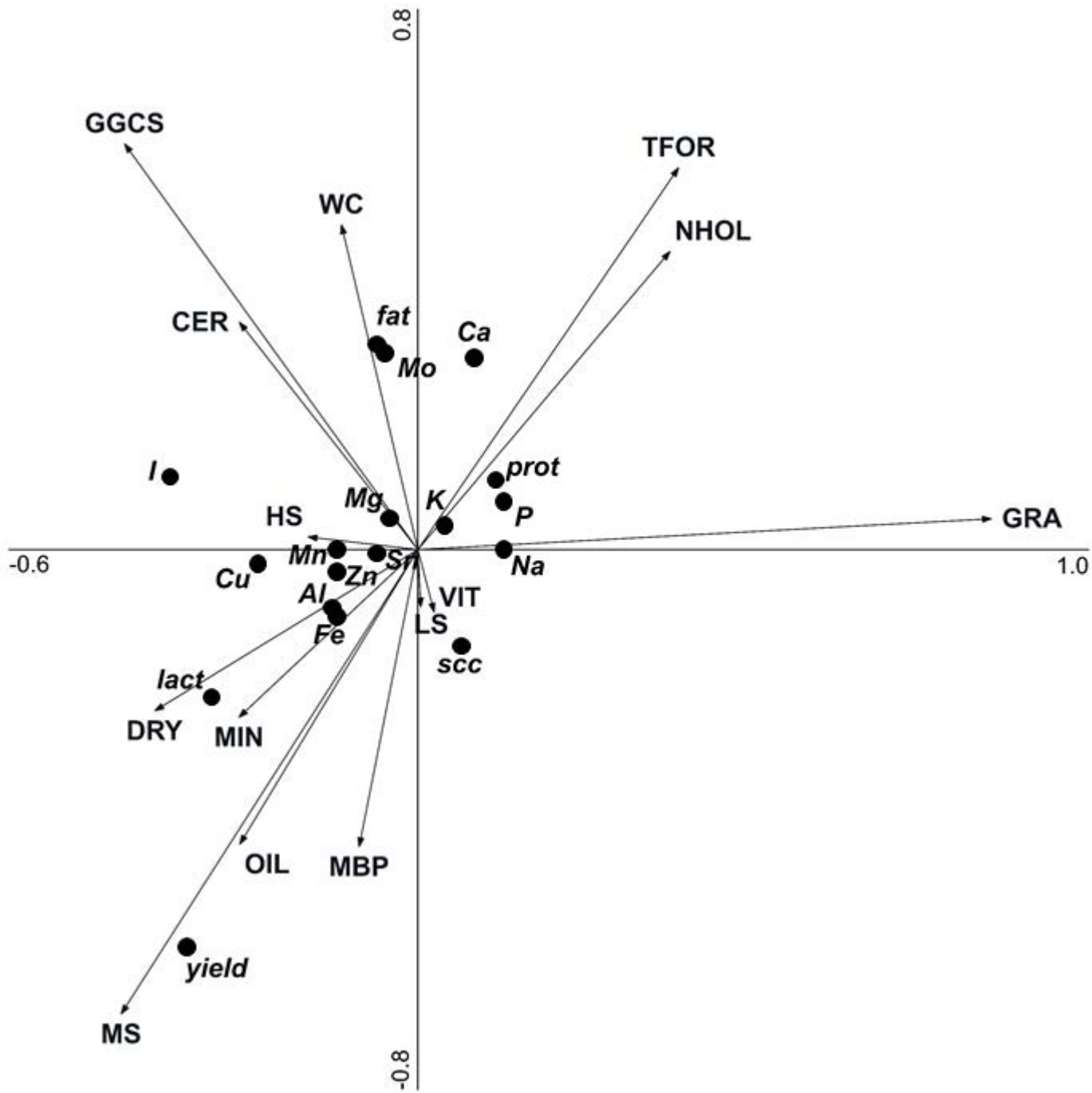


Table S1. Average liveweight for each breed used to estimated total dry matter intake and pasture intake (by difference), as described by Butler et al. (2008)^a

Breed	Liveweight (kg)	Source
Holstein	680	https://www.thecattlesite.com/breeds/dairy/22/holstein/
British Friesian	580	https://www.cows.ie/british-friesian-cattle/
New Zealand Friesian	468	https://www.crv4all-international.com/wp-content/uploads/2016/02/229-14-info-rassen-NZ-Genetics.pdf
Jersey	425	https://www.thecattlesite.com/breeds/dairy/23/jersey/
Scandinavian Red	548	http://www.thecattlesite.com/breeds/dairy/37/norwegian-red/
Shorthorn	600	https://www.vetstream.com/treat/bovis/breeds-pages/shorthorn
Ayrshire	544	https://www.thecattlesite.com/breeds/dairy/19/ayrshire/
Montbeliarde	685	https://www.thecattlesite.com/breeds/dairy/27/montbliarde/
Brown Swiss	590	https://www.thecattlesite.com/breeds/dairy/31/brown-swiss/
Guernsey	475	https://www.thecattlesite.com/breeds/dairy/21/guernsey/
Other breed	560	Average of all other breeds
Crossbreed	560	Average of all other breeds

^a Butler, G., Nielsen, J., Slots, T., Seal, C., Eyre, M., Sanderson, R., & Leifert, C. (2008). Fatty acid and fat-soluble antioxidant concentrations in milk from high- and low-input conventional and organic systems: seasonal variation. *Journal of Science of Food and Agriculture*, 88, 1431-1441

Table S2. Changes of average milk yield, basic composition and macromineral and trace element composition of conventional farms over time.

Parameter	Mean ¹												SE	<i>p</i> -value ²
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec		
Yield and basic composition														
Milk yield (kg/cow/d)	30.4 ^{abc}	29.5 ^{cd}	30.5 ^a	30.1 ^{abc}	30.3 ^{ab}	29.6 ^{bcd}	29.9 ^{abcd}	29.2 ^{def}	28.7 ^{ef}	28.5 ^f	28.4 ^f	29.8 ^{cde}	0.67	<0.001
Fat (g/kg milk)	40.2 ^{abc}	39.0 ^{cd}	39.5 ^{bc}	38.9 ^{cd}	37.9 ^e	38.3 ^{de}	36.6 ^f	38.9 ^{cd}	39.0 ^{cd}	40.6 ^a	41.1 ^a	40.2 ^{ab}	0.40	<0.001
Protein (g/kg milk)	33.6 ^b	33.6 ^c	33.1 ^d	33.0 ^d	32.8 ^e	32.5 ^{ef}	32.3 ^f	32.6 ^e	33.4 ^c	34.5 ^b	35.0 ^a	34.3 ^b	0.18	<0.001
Lactose (g/kg milk)	45.5 ^a	45.3 ^b	45.5 ^a	45.3 ^b	45.3 ^b	45.2 ^b	45.2 ^b	44.9 ^{cd}	44.9 ^d	45.0 ^{cd}	45.0 ^c	45.1 ^c	0.09	<0.001
SCC (×1000/ml milk)	154.0 ^{abc}	131.5 ^c	157.7 ^{ab}	164.7 ^{ab}	150.2 ^{abc}	174.5 ^{abc}	149.0 ^a	161.6 ^{ab}	117.3 ^d	146.4 ^{abc}	148.4 ^{abc}	143.9 ^{bc}	7.50	<0.001
Macrominerals (mg/kg milk)														
Ca	951.0 ^c	969.4 ^c	1044.3 ^{ab}	950.0 ^c	971.6 ^c	911.5 ^d	1035.1 ^{ab}	971.0 ^c	1055.0 ^{ab}	1056.9 ^a	1007.6 ^b	1028.2 ^{ab}	12.76	<0.001
K	1244.6 ^d	1341.5 ^c	1406.8 ^{ab}	1331.1 ^c	1366.2 ^{bcd}	1260.2 ^d	1445.3 ^a	1348.1 ^c	1429.0 ^a	1427.4 ^a	1335.0 ^c	1415.8 ^a	16.29	<0.001
Mg	89.8 ^f	90.9 ^{ef}	101.2 ^{ab}	90.3 ^f	94.3 ^d	85.5 ^g	98.5 ^{bc}	93.9 ^{de}	102.8 ^{ab}	104.3 ^a	102.1 ^{ab}	94.9 ^{cd}	1.32	<0.001
Na	281.7 ^g	315.0 ^{ef}	383.1 ^b	354.7 ^c	330.8 ^d	309.9 ^f	405.8 ^a	327.3 ^{de}	351.8 ^c	362.9 ^c	349.3 ^c	351.3 ^c	6.14	<0.001
P	685.3 ^g	782.2 ^{de}	842.9 ^a	795.2 ^{cd}	810.9 ^{bcd}	729.3 ^f	829.7 ^{ab}	760.5 ^e	814.4 ^{bcd}	808.7 ^{bcd}	794.0 ^{cd}	858.5 ^{ab}	10.64	<0.001
Essential trace elements (µg/kg milk unless otherwise stated)														
Cu	84.2 ^{bc}	49.9 ^d	119.9 ^a	51.8 ^d	45.8 ^{de}	42.6 ^{ef}	74.2 ^c	79.6 ^b	37.6 ^f	44.8 ^{de}	52.0 ^d	45.2 ^{de}	3.76	<0.001
Fe (mg/kg milk)	6.85 ^a	0.68 ^{de}	2.97 ^b	0.47 ^{de}	0.22 ^e	0.27 ^e	9.55 ^a	1.71 ^{bc}	0.29 ^{de}	0.27 ^e	1.03 ^{cd}	0.37 ^{de}	0.589	<0.001
I	400.4 ^a	373.9 ^{abc}	426.4 ^{ab}	334.5 ^{cd}	269.1 ^{ef}	316.2 ^{cde}	269.4 ^f	295.5 ^{def}	326.6 ^{bcd}	367.0 ^{ab}	316.1 ^{de}	282.6 ^{ef}	34.31	<0.001
Mn	105.9 ^a	27.5 ^c	101.1 ^a	25.8 ^{cd}	20.0 ^{de}	19.6 ^{de}	104.4 ^{ab}	53.9 ^b	19.4 ^e	20.1 ^{cde}	24.6 ^{cde}	19.6 ^{de}	7.19	<0.001
Mo	67.7 ^{cd}	45.9 ^{gh}	106.0 ^a	51.3 ^{efg}	50.9 ^{ef}	49.3 ^{efgh}	70.4 ^c	88.9 ^b	44.1 ^h	50.0 ^{efgh}	55.8 ^{de}	47.9 ^{fgh}	2.72	<0.001
Zn (mg/kg milk)	5.87 ^c	4.03 ^{def}	8.81 ^a	4.22 ^{de}	3.93 ^{def}	4.39 ^d	6.07 ^c	7.04 ^b	3.61 ^f	3.96 ^{def}	4.32 ^{de}	3.80 ^{ef}	0.211	<0.001
Non-essential trace elements														
Al (mg/kg milk)	4.38 ^a	0.37 ^{cd}	3.57 ^b	0.32 ^{cd}	0.07 ^d	0.08 ^d	3.46 ^b	0.67 ^c	0.19 ^{cd}	0.14 ^d	0.40 ^{cd}	0.15 ^{cd}	0.368	<0.001
Sn (µg/kg milk)	4.26 ^{bc}	1.48 ^{ef}	4.73 ^a	2.11 ^{cde}	3.26 ^{bcd}	1.53 ^{ef}	3.26 ^{de}	2.55 ^{cde}	1.33 ^f	1.95 ^{ef}	1.64 ^{ef}	75.88 ^{ab}	6.070	<0.001

¹The means of milk yield, fat, protein and lactose contents are the predicted means obtained from the fitted mixed linear model. The means of somatic cell count (SCC), macrominerals and trace elements are the arithmetic means of the measured values. The model included month as fixed factor and farm ID as random factor.

²The *p*-value of SCC was obtained from the fitted mixed linear model based on log(x)-transformed values. The *p*-values of macrominerals and trace elements were obtained from the fitted mixed linear model based on the log(x+1)-transformed values. Different letters indicate significant (*p* < 0.05) difference between months.

Table S3. Changes of average milk yield, basic composition and macromineral and trace element composition of organic farms over time.

Parameter	Mean ¹												SE	<i>p</i> -value ²
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec		
Yield and basic composition														
Milk yield (kg/cow/d)	21.8	21.9	21.1	23.7	23.8	22.6	21.6	21.6	21.8	21.8	22.3	22.5	0.95	0.073
Fat (g/kg milk)	40.8 ^{bcd}	40.0 ^{cd}	39.9 ^d	38.3 ^e	37.4 ^{ef}	38.2 ^{ef}	37.0 ^f	39.9 ^{cd}	41.3 ^{ab}	41.4 ^{ab}	42.1 ^a	41.0 ^{abc}	0.55	<0.001
Protein (g/kg milk)	33.0 ^{bc}	33.0 ^{bc}	32.5 ^c	33.2 ^{bc}	33.1 ^{bc}	33.0 ^{bc}	32.5 ^c	33.6 ^{bc}	33.3 ^b	33.6 ^{bc}	34.3 ^a	33.6 ^{bc}	0.39	<0.001
Lactose (g/kg milk)	45.1 ^{bcd}	45.1 ^{bcd}	45.4 ^a	45.3 ^{ab}	45.2 ^{abc}	44.9 ^{cd}	44.4 ^{ef}	44.1 ^f	44.3 ^f	44.7 ^{de}	44.9 ^{bcd}	44.9 ^{bcd}	0.17	<0.001
SCC (×1000/ml milk)	138.2 ^{ab}	121.4 ^b	152.4 ^a	129.1 ^{ab}	127.7 ^{ab}	150.3 ^a	146.9 ^a	156.8 ^a	109.8 ^c	137.2 ^a	133.3 ^{ab}	128.4 ^{ab}	11.67	<0.001
Macrominerals (mg/kg milk)														
Ca	974.1 ^{ef}	1005.4 ^{de}	1087.7 ^b	1019.4 ^{cd}	1009.7 ^{de}	948.7 ^f	1093.1 ^b	1060.4 ^{bc}	1091.8 ^b	1153.0 ^a	1088.2 ^b	1062.8 ^b	14.75	<0.001
K	1177.1 ^g	1308.2 ^c	1392.8 ^{cd}	1369.9 ^d	1388.7 ^d	1250.2 ^f	1488.6 ^{ab}	1425.2 ^{cd}	1445.1 ^{bc}	1532.0 ^a	1405.5 ^{cd}	1419.7 ^{cd}	19.97	<0.001
Mg	85.3 ^e	91.6 ^d	100.3 ^{bc}	89.9 ^d	92.1 ^d	84.9 ^{ef}	100.1 ^{bc}	97.1 ^c	99.1 ^{bc}	105.4 ^a	102.1 ^{ab}	92.4 ^d	1.49	<0.001
Na	265.6 ^h	323 ^f	376.5 ^b	355.3 ^{bcd}	329.3 ^{ef}	309.4 ^g	416.6 ^a	349.8 ^{cde}	355.4 ^{bcd}	366.5 ^{bc}	346.5 ^{cde}	343.2 ^{de}	9.12	<0.001
P	644.5 ^e	772.7 ^c	842.2 ^{ab}	841.7 ^{ab}	835.6 ^{ab}	737.6 ^d	858.6 ^a	819.4 ^b	811.7 ^b	837.2 ^{ab}	816.5 ^b	863.6 ^a	11.70	<0.001
Essential trace elements (µg/kg milk unless otherwise stated)														
Cu	43.5 ^{cd}	106.4 ^a	100.0 ^a	47.8 ^b	36.0 ^{cd}	36.6 ^{cd}	31.1 ^d	42.5 ^{cd}	48.5 ^b	42.8 ^{cd}	49.2 ^b	48.7 ^b	4.15	<0.001
Fe (mg/kg milk)	1.69 ^a	1.16 ^a	0.83 ^{ab}	0.33 ^{cd}	0.20 ^d	0.24 ^{cd}	1.72 ^{ab}	0.59 ^{bc}	0.32 ^{cd}	0.22 ^d	0.33 ^{cd}	0.28 ^{cd}	0.181	<0.001
I	464.4 ^a	406.4 ^{ab}	485.1 ^{ab}	345.3 ^{de}	272.9 ^{fg}	277.6 ^{efg}	247.9 ^g	301.3 ^{ef}	346.2 ^{cd}	442.2 ^{ab}	400.2 ^{ab}	383.8 ^{bc}	72.39	<0.001
Mn	36.4 ^c	71.5 ^a	47.3 ^b	22.1 ^d	17.4 ^e	20.3 ^{de}	28.1 ^d	24.9 ^d	21.7 ^{de}	17.4 ^c	20.4 ^{de}	19.3 ^{de}	2.87	<0.001
Mo	56.9 ^d	142.0 ^a	105.2 ^b	67.3 ^{cd}	59.5 ^d	59.6 ^d	46.8 ^e	65.6 ^{cd}	66.3 ^{cd}	65.2 ^{cd}	76.2 ^c	74.0 ^c	5.31	<0.001
Zn (mg/kg milk)	3.65 ^{de}	8.86 ^a	7.29 ^b	3.95 ^{cd}	3.40 ^{de}	4.31 ^c	3.17 ^e	4.01 ^{cd}	4.39 ^c	3.53 ^{de}	3.92 ^{cd}	3.93 ^{cd}	0.242	<0.001
Non-essential trace elements														
Al (mg/kg milk)	0.76 ^a	0.77 ^a	0.61 ^{ab}	0.17 ^{cd}	0.06 ^d	0.10 ^{cd}	0.49 ^{bc}	0.22 ^{cd}	0.17 ^{cd}	0.12 ^{cd}	0.18 ^{cd}	0.13 ^{cd}	0.101	<0.001
Sn (µg/kg milk)	2.08 ^{bcd}	3.48 ^a	3.30 ^{ab}	2.04 ^{bcd}	2.51 ^{abc}	1.56 ^{de}	4.75 ^c	1.87 ^{cde}	2.57 ^{de}	1.37 ^{de}	1.72 ^{bcd}	4.86 ^{ab}	0.872	<0.001

¹The means of milk yield, fat, protein and lactose contents are the predicted means obtained from the fitted mixed linear model. The means of somatic cell count (SCC), macrominerals and trace elements are the arithmetic means of the measured values. The model included month as fixed factor and farm ID as random factor.

²The *p*-value of SCC was obtained from the fitted mixed linear model based on log(x)-transformed values. The *p*-values of macrominerals and trace elements were obtained from the fitted mixed linear model based on the log(x+1)-transformed values. Different letters indicate significant (*p* < 0.05) difference between months.

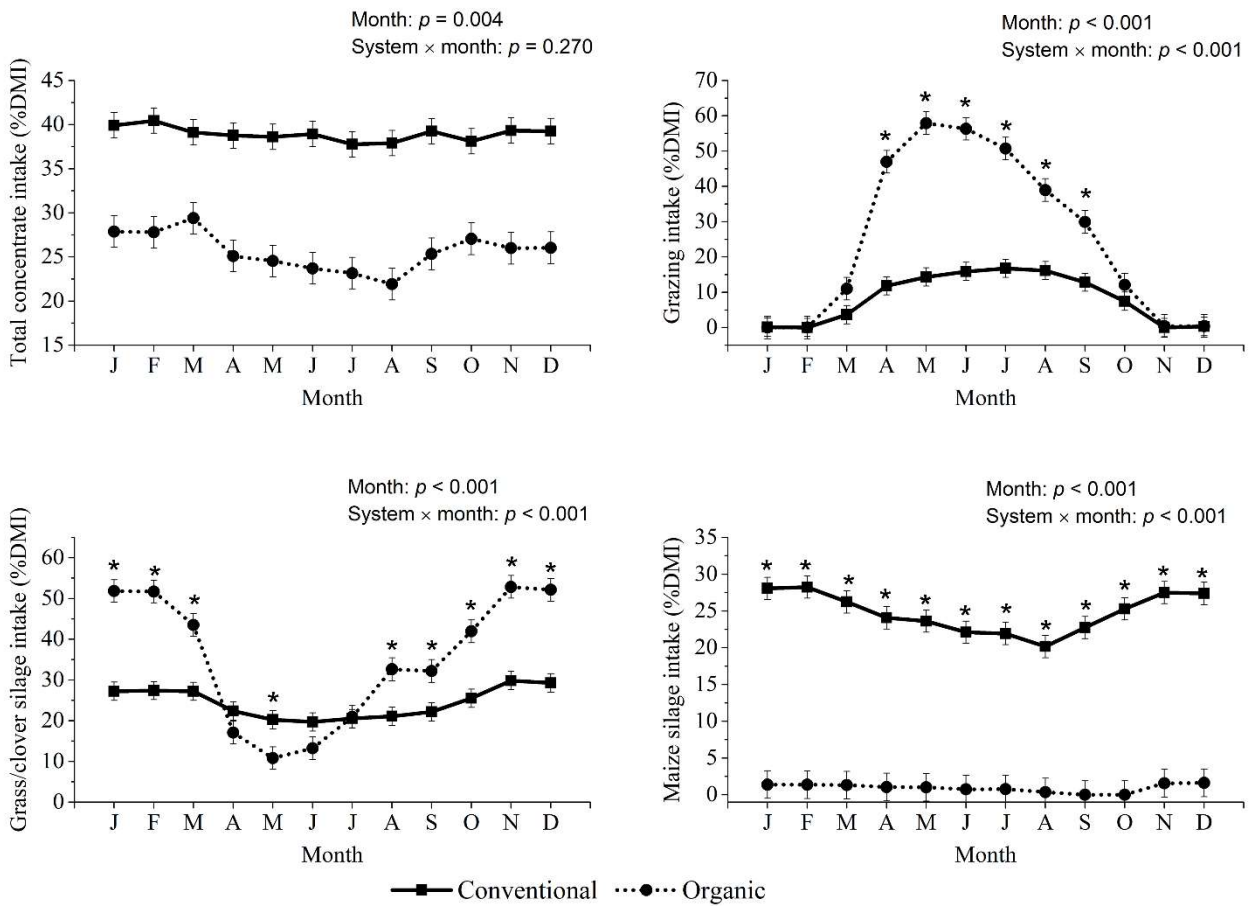


Figure S1. Intakes of concentrate, grazing, grass/clover silage, and maize silage in conventional and organic farms. Means are the predicted means from the fitted mixed linear model. The error bars represent the standard error obtained from the same linear model. *: significant difference between conventional and organic farms within the month ($p < 0.05$).

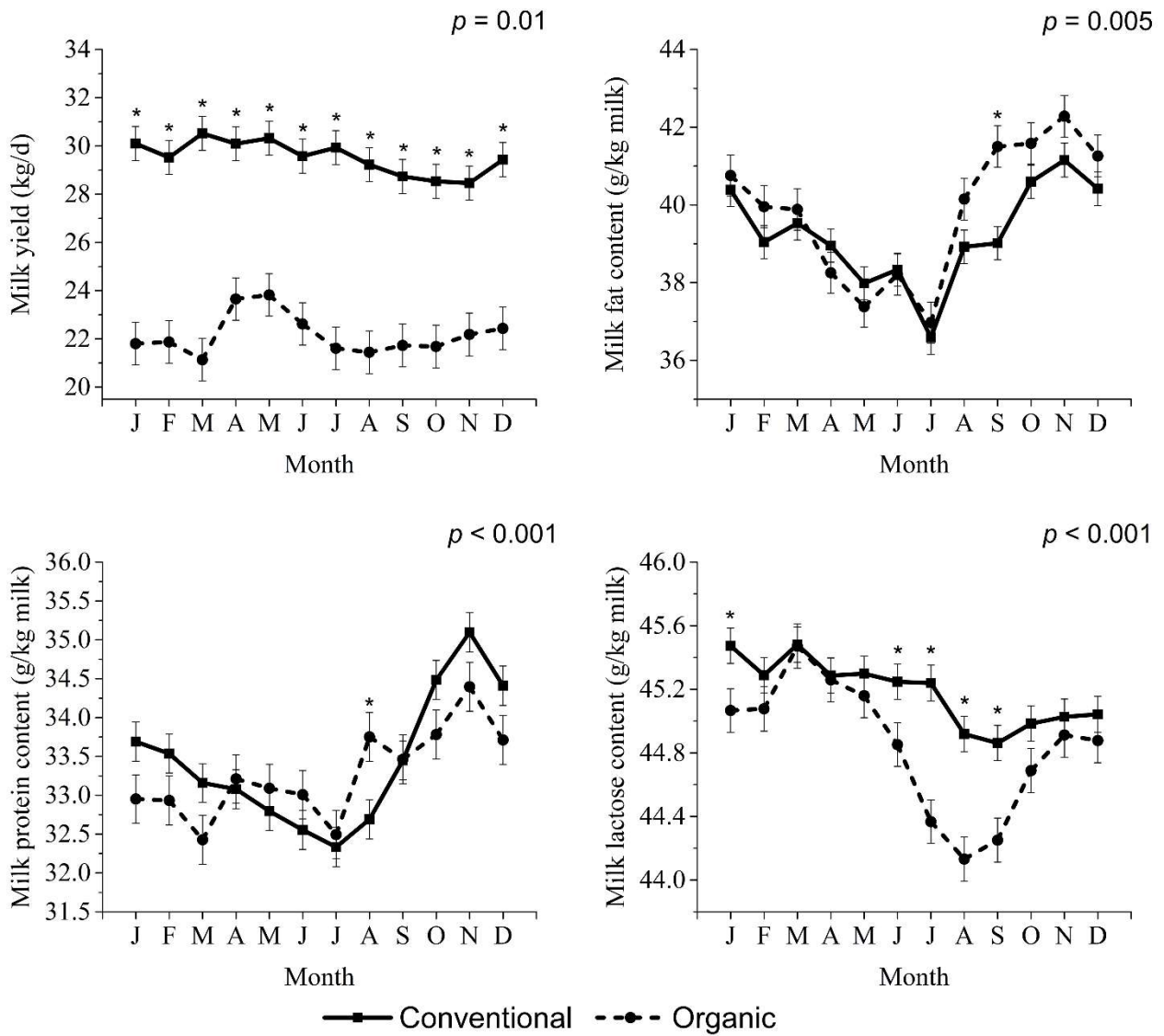


Figure S2. Significant interactions between production system and month of milk yield and composition. Means are the predicted means from the fitted mixed linear model. The error bars represent the standard error obtained from the same linear model. *: significant difference between conventional and organic farms within the month ($p < 0.05$).