SUPPLEMENTARY MATERIALS

Table S1. Carbon footprint (CFP) of common feed raw materials used for calculating the CFP of diets used in experiment 3.

Item	CFP (g CO_2-eq/kg)
Corn grain meal	560.00
Wheat middlings	276.00
Barley grain meal	434.00
Wheat	455.00
Beet pulp	357.00
Dried alfalfa	217.00
Palm oil	2805.00
Soybean meal	4152.00
Slow-release urea	1136.20

Table S2. Total gas production (mL) measured in an *in vitro* fermentation model

Treatment		High-forage ration				High-grain ration			
N-source	[1]N-level	0-6 h	0-9 h	0-12 h	0-24h	0-6 h	0-9 h	0-12 h	0-24h
Control	-	32.90 (±0.33)[ab]	75.70 (±0.94)	108.90 (±0.64)[ab]	148.13 (±0.59)[ab]	37.70 (±1.07)[b]	82.70 (±1.69)[f]	118.70 (±1.96)[e]	169.90 (±2.49)[e]
SBM	Low	32.60 (±0.62)[ab]	75.00 (±0.35)	108.60 (±0.29)[ab]	147.20 (±0.90)[ab]	38.90 (±0.53)[ab]	84.50 (±0.76)[def]	120.70 (±0.72)[de]	173.90 (±0.86)[de]
SBM	Medium	33.20 (±0.46)[a]	74.40 (±1.07)	107.40 (±1.35)[ab]	147.80 (±1.74)[ab]	39.70 (±0.58)[ab]	83.90 (±1.00)[ef]	119.90 (±1.10)[e]	170.70 (±0.89)[de]
SBM	High	32.80 (±0.20)[ab]	75.40 (±0.51)	108.60 (±1.03)[ab]	149.80 (±0.97)[ab]	40.20 (±0.58)[ab]	85.60 (±0.91)[def]	121.40 (±1.54)[de]	171.80 (±2.25)[de]
SRU	Low	31.20 (±0.56)[ab]	73.40 (±0.29)	106.40 (±0.53)[ab]	146.20 (±0.75)[ab]	41.60 (±1.18)[ab]	91.00 (±2.58)[cdef]	125.20 (±2.77)[cde]	176.20 (±2.78)[cde]
SRU	Medium	31.40 (±0.33)[ab]	74.40 (±0.93)	107.40 (±1.23)[ab]	146.00 (±1.48)[ab]	41.20 (±1.57)[ab]	94.00 (±3.05)[bcd]	130.00 (±2.93)[bcd]	180.60 (±2.60)[bcd]
SRU	High	30.90 (±0.64)[ab]	72.90 (±0.78)	105.70 (±0.54)[b]	144.90 (±0.81)[b]	42.80 (±1.47)[b]	96.60 (±4.23)[bc]	133.10 (±4.09)[bc]	185.10 (±4.09)[abc]
Urea	Low	31.90 (±0.68)[ab]	76.70 (±0.73)	110.70 (±0.66)[a]	149.70 (±0.89)[ab]	43.00 (±0.91)[b]	93.40 (±1.46)[cde]	128.20 (±1.83)[cde]	178.20 (±2.23)[cde]
Urea	Medium	30.50 (±0.77)[ab]	74.70 (±1.45)	110.30 (±1.92)[ab]	150.10 (±1.73)[ab]	43.10 (±0.71)[b]	103.50 (±0.59)[ab]	138.30 (±0.70)[ab]	189.10 (±0.46)[ab]
Urea	High	30.25 (±0.97)[b]	74.75 (±1.36)	109.75 (±1.16)[ab]	151.75 (±1.01)[a]	43.40 (±0.73)[b]	106.60 (±0.53)[a]	144.40 (±0.53)[a]	194.80 (±1.06)[a]

[a-e] Different letters within same column are significantly different ($P < 0.05$).

N: nitrogen; SBM: soybean meal; SRU: slow-release urea

[1]N-level: low, medium and high nitrogen levels correspond to 1.07 mg N, 3.22 mg N and 5.35 mg N, respectively.

Table S3. Acetate concentration (mM) measured in an *in vitro* fermentation model

Treatment		High-forage ration			High-grain ration		
N-source	[1]N-level	0 h	9 h	12 h	0 h	9 h	12 h
Control	-	6.02 (±0.30)	33.23 (±0.87)	41.56 (±1.25)	5.75 (±0.15)	29.99 (±1.17)	38.24 (±0.23)[ab]
SBM	Low	6.02 (±0.30)	32.85 (±0.16)	41.98 (±0.44)	5.75 (±0.15)	29.82 (±0.52)	38.85 (±0.30)[ab]
SBM	Medium	6.02 (±0.30)	33.48 (±0.39)	41.45 (±0.51)	5.75 (±0.15)	29.21 (±0.21)	38.34 (±0.27)[ab]
SBM	High	6.02 (±0.30)	33.52 (±0.55)	42.19 (±0.37)	5.75 (±0.15)	29.88 (±0.24)	39.67 (±0.26)[a]
SRU	Low	6.02 (±0.30)	32.08 (±0.42)	41.61 (±0.18)	5.75 (±0.15)	30.22 (±1.09)	38.82 (±0.36)[ab]
SRU	Medium	6.02 (±0.30)	34.33 (±1.98)	42.47 (±0.31)	5.75 (±0.15)	31.02 (±0.76)	38.28 (±0.38)[ab]
SRU	High	6.02 (±0.30)	32.14 (±0.33)	41.35 (±0.53)	5.75 (±0.15)	30.96 (±0.87)	37.91 (±0.47)[c]
Urea	Low	6.02 (±0.30)	34.10 (±0.91)	42.38 (±0.33)	5.75 (±0.15)	30.05 (±0.07)	38.56 (±0.29)[ab]
Urea	Medium	6.02 (±0.30)	33.31 (±0.43)	41.76 (±0.41)	5.75 (±0.15)	30.96 (±0.42)	38.33 (±0.56)[ab]
Urea	High	6.02 (±0.30)	32.93 (±0.46)	41.77 (±0.45)	5.75 (±0.15)	31.28 (±0.61)	38.35 (±0.28)[ab]

[a–c] Different letters within same column are significantly different ($P < 0.05$).

N: nitrogen; SBM: soybean meal; SRU: slow-release urea

[1]N-level: low, medium and high nitrogen levels correspond to 1.07 mg N, 3.22 mg N and 5.35 mg N, respectively.

Table S4. Propionate concentration (mM) measured in an *in vitro* fermentation model							
Treatment		**High-forage ration**			**High-grain ration**		
N-source	**[1]N-level**	**0 h**	**9 h**	**12 h**	**0 h**	**9 h**	**12 h**
Control	-	0.91 (±0.01)	20.85 (± 0.65)	36.56 (± 1.18)	0.94 (± 0.02)	18.00 (±0.63)	36.21 (±0.54)
SBM	Low	0.91 (±0.01)	20.75 (± 0.13)	37.36 (± 0.38)	0.94 (± 0.02)	17.77 (±0.37)	36.41 (±0.34)
SBM	Medium	0.91 (±0.01)	21.42 (± 0.26)	36.29 (± 0.73)	0.94 (± 0.02)	17.39 (±0.16)	36.53 (±0.52)
SBM	High	0.91 (±0.01)	21.62 (± 0.19)	37.08 (± 0.17)	0.94 (± 0.02)	17.76 (±0.14)	37.78 (±0.25)
SRU	Low	0.91 (±0.01)	20.49 (± 0.29)	36.41 (± 0.40)	0.94 (± 0.02)	17.97 (±0.79)	36.50 (±0.47)
SRU	Medium	0.91 (±0.01)	20.90 (± 0.47)	37.63 (± 0.35)	0.94 (± 0.02)	18.98 (±0.52)	37.09 (±0.32)
SRU	High	0.91 (±0.01)	20.44 (± 0.22)	36.46 (± 0.34)	0.94 (± 0.02)	18.31 (±0.54)	36.55 (±0.64)
Urea	Low	0.91 (±0.01)	21.87 (± 0.74)	37.13 (± 0.38)	0.94 (± 0.02)	18.07 (±0.20)	36.62 (±0.54)
Urea	Medium	0.91 (±0.01)	21.33 (± 0.34)	36.63 (± 0.60)	0.94 (± 0.02)	18.72 (±0.26)	37.62 (±0.81)
Urea	High	0.91 (±0.01)	21.25 (± 0.23)	36.26 (± 0.43)	0.94 (± 0.02)	18.90 (±0.44)	38.15 (±0.53)

Statistically significant differences were not observed within the same column

N: nitrogen; SBM: soybean meal; SRU: slow-release urea

[1]N-level: low, medium and high nitrogen levels correspond to 1.07 mg N, 3.22 mg N and 5.35 mg N, respectively.

Table S5. Isobutyric acid concentration (mM) measured in an in vitro fermentation model

Treatment		High-forage ration			High-grain ration		
N-source	[1]N-level	0 h	9 h	12 h	0 h	9 h	12 h
Control	-	0.00 (±0.00)	0.00 (±0.00)	0.19 (±0.01)	0.00 (±0.00)	0.00 (±0.00)	0.00 (±0.00)
SBM	Low	0.00 (±0.00)	0.00 (±0.00)	0.19 (±0.01)	0.00 (±0.00)	0.00 (±0.00)	0.00 (±0.00)
SBM	Medium	0.00 (±0.00)	0.00 (±0.00)	0.19 (±0.00)	0.00 (±0.00)	0.00 (±0.00)	0.00 (±0.00)
SBM	High	0.00 (±0.00)	0.00 (±0.00)	0.19 (±0.01)	0.00 (±0.00)	0.00 (±0.00)	0.00 (±0.00)
SRU	Low	0.00 (±0.00)	0.00 (±0.00)	0.19 (±0.01)	0.00 (±0.00)	0.00 (±0.00)	0.00 (±0.00)
SRU	Medium	0.00 (±0.00)	0.00 (±0.00)	0.19 (±0.01)	0.00 (±0.00)	0.00 (±0.00)	0.00 (±0.00)
SRU	High	0.00 (±0.00)	0.00 (±0.00)	0.20 (±0.00)	0.00 (±0.00)	0.00 (±0.00)	0.00 (±0.00)
Urea	Low	0.00 (±0.00)	0.00 (±0.00)	0.19 (±0.01)	0.00 (±0.00)	0.00 (±0.00)	0.00 (±0.00)
Urea	Medium	0.00 (±0.00)	0.00 (±0.00)	0.19 (±0.00)	0.00 (±0.00)	0.00 (±0.00)	0.00 (±0.00)
Urea	High	0.00 (±0.00)	0.00 (±0.00)	0.18 (±0.01)	0.00 (±0.00)	0.00 (±0.00)	0.00 (±0.00)

Statistically significant differences were not observed within the same column

N: nitrogen; SBM: soybean meal; SRU: slow-release urea

[1]N-level: low, medium and high nitrogen levels correspond to 1.07 mg N, 3.22 mg N and 5.35 mg N, respectively.

Table S6. Butyrate concentration (mM) measured in an *in vitro* fermentation model							
Treatment		**High-forage ration**			**High-grain ration**		
N-source	**[1]N-level**	**0 h**	**9 h**	**12 h**	**0 h**	**9 h**	**12 h**
Control	-	0.68 (±0.01)	3.61 (±0.10)[ab]	8.68 (±0.26)	0.71 (±0.01)	4.26 (±0.13)[cde]	7.61 (±0.08)[bcd]
SBM	Low	0.68 (±0.01)	3.50 (±0.02)[ab]	8.66 (±0.11)	0.71 (±0.01)	4.18 (±0.08)[cde]	7.69 (±0.06)[bcd]
SBM	Medium	0.68 (±0.01)	3.47 (±0.06)[ab]	8.41 (±0.14)	0.71 (±0.01)	4.01 (±0.03)[de]	7.36 (±0.06)[d]
SBM	High	0.68 (±0.01)	3.40 (±0.05)[b]	8.37 (±0.16)	0.71 (±0.01)	3.97 (±0.04)[e]	7.54 (±0.06)[cd]
SRU	Low	0.68 (±0.01)	3.49 (±0.04)[ab]	8.65 (±0.07)	0.71 (±0.01)	4.49 (±0.20)[bcd]	7.89 (±0.16)[bcd]
SRU	Medium	0.68 (±0.01)	3.61 (±0.06)[ab]	8.97 (±0.09)	0.71 (±0.01)	4.77 (±0.09)[ab]	8.06 (±0.19)[bc]
SRU	High	0.68 (±0.01)	3.56 (±0.03)[ab]	8.64 (±0.11)	0.71 (±0.01)	4.65 (±0.11)[abc]	7.97 (±0.13)[bcd]
Urea	Low	0.68 (±0.01)	3.75 (±0.14)[a]	8.94 (±0.06)	0.71 (±0.01)	4.55 (±0.04)[bc]	7.96 (±0.10)[bcd]
Urea	Medium	0.68 (±0.01)	3.66 (±0.06)[ab]	8.97 (±0.11)	0.71 (±0.01)	4.81 (±0.06)[ab]	8.20 (±0.22)[ab]
Urea	High	0.68 (±0.01)	3.62 (±0.04)[ab]	8.96 (±0.09)	0.71 (±0.01)	5.05 (±0.13)[a]	8.71 (±0.13)[a]

[a–c] Different letters within same column are significantly different ($P < 0.05$).

N: nitrogen; SBM: soybean meal; SRU: slow-release urea

[1]N-level: low, medium and high nitrogen levels correspond to 1.07 mg N, 3.22 mg N and 5.35 mg N, respectively.

Table S7. Total short-chain fatty acids concentration (mM) measured in an *in vitro* fermentation model							
Treatment		**High-forage ration**			**High-grain ration**		
N-source	**[1]N-level**	**0 h**	**9 h**	**12 h**	**0 h**	**9 h**	**12 h**
Control	-	13.45 (±1.03)	86.51 (±2.08)	91.04 (±2.72)	11.63 (±0.50)	87.32 (±3.22)	101.88 (±2.26)[c]
SBM	Low	13.45 (±1.03)	84.33 (±0.38)	91.95 (±0.87)	11.63 (±0.50)	87.20 (±1.68)	103.14 (±0.45)[c]
SBM	Medium	13.45 (±1.03)	85.58 (±1.45)	90.49 (±1.49)	11.63 (±0.50)	85.94 (±0.75)	101.71 (±0.88)[c]
SBM	High	13.45 (±1.03)	83.36 (±1.25)	91.56 (±0.68)	11.63 (±0.50)	86.72 (±0.82)	104.07 (±0.94)[c]
SRU	Low	13.45 (±1.03)	83.03 (±1.01)	90.86 (±0.71)	11.63 (±0.50)	96.45 (±5.29)	110.84 (±3.43)[bc]
SRU	Medium	13.45 (±1.03)	85.21 (±1.81)	93.18 (±0.56)	11.63 (±0.50)	100.07 (±2.37)	111.51 (±3.63)[bc]
SRU	High	13.45 (±1.03)	83.20 (±0.67)	90.41 (±0.97)	11.63 (±0.50)	102.57 (±2.93)	117.47 (±4.14)[ab]
Urea	Low	13.45 (±1.03)	88.11 (±2.59)	92.64 (±0.67)	11.63 (±0.50)	97.56 (±1.10)	111.86 (±1.17)[bc]
Urea	Medium	13.45 (±1.03)	87.78 (±1.39)	91.74 (±1.22)	11.63 (±0.50)	111.86 (±2.63)	125.53 (±1.65)[a]
Urea	High	13.45 (±1.03)	85.27 (±1.14)	91.33 (±0.98)	11.63 (±0.50)	113.61 (±3.32)	126.94 (±2.52)[a]

[a–c] Different letters within same column are significantly different ($P < 0.05$).

N: nitrogen; SBM: soybean meal; SRU: slow-release urea

[1]N-level: low, medium and high nitrogen levels correspond to 1.07 mg N, 3.22 mg N and 5.35 mg N, respectively.

Treatment		High-forage ration			High-grain ration		
N-source	**[1]N-level**	**0 h**	**9 h**	**12 h**	**0 h**	**9 h**	**12 h**
Control	-	0.00 (±0.00)	0.08 (±0.00)	0.34 (±0.01)[a]	0.00 (±0.00)	0.06 (±0.02)[ab]	0.13 (±0.03)[ab]
SBM	Low	0.00 (±0.00)	0.08 (±0.00)	0.35 (±0.01)[a]	0.00 (±0.00)	0.07 (±0.01)[a]	0.14 (±0.01)[a]
SBM	Medium	0.00 (±0.00)	0.09 (±0.00)	0.33 (±0.01)[a]	0.00 (±0.00)	0.06 (±0.01)[ab]	0.14 (±0.01)[a]
SBM	High	0.00 (±0.00)	0.08 (±0.01)	0.31 (±0.01)[ab]	0.00 (±0.00)	0.07 (±0.01)[ab]	0.13 (±0.00)[a]
SRU	Low	0.00 (±0.00)	0.07 (±0.02)	0.31 (±0.02)[ab]	0.00 (±0.00)	0.05 (±0.01)[ab]	0.12 (±0.02)[ab]
SRU	Medium	0.00 (±0.00)	0.08 (±0.01)	0.31 (±0.02)[abc]	0.00 (±0.00)	0.06 (±0.01)[ab]	0.13 (±0.02)[ab]
SRU	High	0.00 (±0.00)	0.07 (±0.02)	0.32 (±0.02)[ab]	0.00 (±0.00)	0.05 (±0.01)[ab]	0.08 (±0.03)[abc]
Urea	Low	0.00 (±0.00)	0.08 (±0.01)	0.32 (±0.01)[a]	0.00 (±0.00)	0.05 (±0.01)[ab]	0.13 (±0.01)[ab]
Urea	Medium	0.00 (±0.00)	0.06 (±0.01)	0.25 (±0.01)[c]	0.00 (±0.00)	0.02 (±0.01)[ab]	0.06 (±0.01)[bc]
Urea	High	0.00 (±0.00)	0.07 (±0.01)	0.25 (±0.01)[bc]	0.00 (±0.00)	0.01 (±0.01)[b]	0.02 (±0.01)[c]

Table S8. Isovaleric acid concentration (mM) measured in an *in vitro* fermentation model

[a–c] Different letters within same column are significantly different ($P < 0.05$).

N: nitrogen; SBM: soybean meal; SRU: slow-release urea

[1]N-level: low, medium and high nitrogen levels correspond to 1.07 mg N, 3.22 mg N and 5.35 mg N, respectively.

Table S9. Valeric acid concentration (mM) measured in an *in vitro* fermentation model							
Treatment		**High-forage ration**			**High-grain ration**		
N-source	**[1]N-level**	**0 h**	**9 h**	**12 h**	**0 h**	**9 h**	**12 h**
Control	-	0.00 (±0.00)	0.21 (±0.01)	2.84 (±0.10)	0.00 (±0.00)	0.12 (±0.03)	0.57 (±0.03)
SBM	Low	0.00 (±0.00)	0.20 (±0.01)	2.89 (±0.02)	0.00 (±0.00)	0.16 (±0.01)	0.50 (±0.03)
SBM	Medium	0.00 (±0.00)	0.20 (±0.02)	2.88 (±0.05)	0.00 (±0.00)	0.12 (±0.03)	0.51 (±0.02)
SBM	High	0.00 (±0.00)	0.21 (±0.01)	2.93 (±0.04)	0.00 (±0.00)	0.16 (±0.02)	0.57 (±0.03)
SRU	Low	0.00 (±0.00)	0.15 (±0.04)	2.91 (±0.03)	0.00 (±0.00)	0.14 (±0.04)	0.43 (±0.02)
SRU	Medium	0.00 (±0.00)	0.20 (±0.01)	3.00 (±0.07)	0.00 (±0.00)	0.18 (±0.01)	0.47 (±0.03)
SRU	High	0.00 (±0.00)	0.15 (±0.04)	2.91 (±0.08)	0.00 (±0.00)	0.14 (±0.04)	0.45 (±0.07)
Urea	Low	0.00 (±0.00)	0.21 (±0.02)	3.04 (±0.02)	0.00 (±0.00)	0.13 (±0.03)	0.43 (±0.03)
Urea	Medium	0.00 (±0.00)	0.20 (±0.02)	3.08 (±0.06)	0.00 (±0.00)	0.18 (±0.00)	0.39 (±0.02)
Urea	High	0.00 (±0.00)	0.20 (±0.01)	3.03 (±0.04)	0.00 (±0.00)	0.13 (±0.03)	0.39 (±0.02)

Statistically significant differences were not observed within the same column

N: nitrogen; SBM: soybean meal; SRU: slow-release urea

[1]N-level: low, medium and high nitrogen levels correspond to 1.07 mg N, 3.22 mg N and 5.35 mg N, respectively.

Table S10. Branched volatile fatty acids concentration (mM) measured in an *in vitro* fermentation model

Treatment		High-forage ration			High-grain ration		
N-source	[1]N-level	0 h	9 h	12 h	0 h	9 h	12 h
Control	-	0.00 (±0.00)	0.08 (±0.00)	0.60 (±0.03)[ab]	0.00 (±0.00)	0.06 (±0.02)[ab]	0.13 (±0.03)[ab]
SBM	Low	0.00 (±0.00)	0.08 (±0.00)	0.63 (±0.02)[a]	0.00 (±0.00)	0.07 (±0.01)[a]	0.14 (±0.01)[a]
SBM	Medium	0.00 (±0.00)	0.09 (±0.00)	0.58 (±0.00)[abc]	0.00 (±0.00)	0.06 (±0.01)[ab]	0.14 (±0.01)[a]
SBM	High	0.00 (±0.00)	0.08 (±0.01)	0.58 (±0.02)[abc]	0.00 (±0.00)	0.07 (±0.01)[ab]	0.13 (±0.00)[a]
SRU	Low	0.00 (±0.00)	0.07 (±0.02)	0.56 (±0.03)[abc]	0.00 (±0.00)	0.05 (±0.01)[ab]	0.12 (±0.02)[ab]
SRU	Medium	0.00 (±0.00)	0.08 (±0.01)	0.57 (±0.02)[abc]	0.00 (±0.00)	0.06 (±0.01)[ab]	0.13 (±0.02)[ab]
SRU	High	0.00 (±0.00)	0.07 (±0.02)	0.57 (±0.03)[abc]	0.00 (±0.00)	0.03 (±0.02)[ab]	0.08 (±0.03)[abc]
Urea	Low	0.00 (±0.00)	0.08 (±0.01)	0.59 (±0.02)[abc]	0.00 (±0.00)	0.05 (±0.01)[ab]	0.13 (±0.01)[ab]
Urea	Medium	0.00 (±0.00)	0.06 (±0.01)	0.52 (±0.02)[bc]	0.00 (±0.00)	0.02 (±0.01)[ab]	0.06 (±0.01)[bc]
Urea	High	0.00 (±0.00)	0.07 (±0.01)	0.50 (±0.02)[c]	0.00 (±0.00)	0.01 (±0.01)[b]	0.02 (±0.01)[c]

[a–c] Different letters within same column are significantly different ($P < 0.05$).

N: nitrogen; SBM: soybean meal; SRU: slow-release urea

[1]N-level: low, medium and high nitrogen levels correspond to 1.07 mg N, 3.22 mg N and 5.35 mg N, respectively.

Treatment		High-forage ration			High-grain ration		
N-source	[1]N-level	0 h	9 h	12 h	0 h	9 h	12 h
Control	-	0.00 (±0.00)	0.00 (±0.00)	0.07 (±0.01)	0.00 (±0.00)	0.00 (±0.00)	0.00 (±0.00)
SBM	Low	0.00 (±0.00)	0.00 (±0.00)	0.08 (±0.01)	0.00 (±0.00)	0.00 (±0.00)	0.00 (±0.00)
SBM	Medium	0.00 (±0.00)	0.00 (±0.00)	0.07 (±0.00)	0.00 (±0.00)	0.00 (±0.00)	0.00 (±0.00)
SBM	High	0.00 (±0.00)	0.00 (±0.00)	0.07 (±0.01)	0.00 (±0.00)	0.00 (±0.00)	0.00 (±0.00)
SRU	Low	0.00 (±0.00)	0.00 (±0.00)	0.06 (±0.01)	0.00 (±0.00)	0.00 (±0.00)	0.00 (±0.00)
SRU	Medium	0.00 (±0.00)	0.00 (±0.00)	0.07 (±0.00)	0.00 (±0.00)	0.00 (±0.00)	0.00 (±0.00)
SRU	High	0.00 (±0.00)	0.00 (±0.00)	0.05 (±0.01)	0.00 (±0.00)	0.00 (±0.00)	0.00 (±0.00)
Urea	Low	0.00 (±0.00)	0.00 (±0.00)	0.08 (±0.00)	0.00 (±0.00)	0.00 (±0.00)	0.00 (±0.00)
Urea	Medium	0.00 (±0.00)	0.00 (±0.00)	0.07 (±0.01)	0.00 (±0.00)	0.00 (±0.00)	0.00 (±0.00)
Urea	High	0.00 (±0.00)	0.00 (±0.00)	0.07 (±0.01)	0.00 (±0.00)	0.00 (±0.00)	0.00 (±0.00)

Table S11. 2-methylbutyric acid concentration (mM) measured in an *in vitro* fermentation model

Statistically significant differences were not observed within the same column.

N: nitrogen; SBM: soybean meal; SRU: slow-release urea

[1]N-level: low, medium and high nitrogen levels correspond to 1.07 mg N, 3.22 mg N and 5.35 mg N, respectively.

Table S12. pH measured in an *in vitro* fermentation model

Treatment		High-forage ration			High-grain ration		
N-source	[1]N-level	0 h	9 h	12 h	0 h	9 h	12 h
Control	-	6.93 (±0.00)	6.49 (±0.01)	6.54 (±0.01)	6.93 (±0.00)	6.39 (±0.03)[a]	6.25 (±0.04)[a]
SBM	Low	6.93 (±0.00)	6.48 (±0.01)	6.54 (±0.01)	6.93 (±0.00)	6.36 (±0.01)[ab]	6.21 (±0.01)[a]
SBM	Medium	6.93 (±0.00)	6.51 (±0.02)	6.56 (±0.01)	6.93 (±0.00)	6.37 (±0.01)[ab]	6.25 (±0.02)[a]
SBM	High	6.93 (±0.00)	6.50 (±0.01)	6.56 (±0.01)	6.93 (±0.00)	6.37 (±0.02)[ab]	6.23 (±0.02)[a]
SRU	Low	6.93 (±0.00)	6.52 (±0.01)	6.57 (±0.01)	6.93 (±0.00)	6.27 (±0.03)[abc]	6.12 (±0.03)[ab]
SRU	Medium	6.93 (±0.00)	6.50 (±0.02)	6.56 (±0.01)	6.93 (±0.00)	6.23 (±0.05)[bc]	6.11 (±0.05)[ab]
SRU	High	6.93 (±0.00)	6.50 (±0.02)	6.58 (±0.02)	6.93 (±0.00)	6.17 (±0.06)[cd]	6.00 (±0.08)[bcd]
Urea	Low	6.93 (±0.00)	6.50 (±0.00)	6.54 (±0.00)	6.93 (±0.00)	6.23 (±0.02)[abc]	6.10 (±0.02)[abc]
Urea	Medium	6.93 (±0.00)	6.52 (±0.01)	6.57 (±0.01)	6.93 (±0.00)	6.04 (±0.03)[d]	5.92 (±0.04)[cd]
Urea	High	6.93 (±0.00)	6.54 (±0.01)	6.59 (±0.02)	6.93 (±0.00)	6.02 (±0.02)[d]	5.88 (±0.02)[d]

[a–d] Different letters within same column are significantly different ($P < 0.05$).

N: nitrogen; SBM: soybean meal; SRU: slow-release urea

[1]N-level: low, medium and high nitrogen levels correspond to 1.07 mg N, 3.22 mg N and 5.35 mg N, respectively.

Table S13. Ammonia concentration (mM) measured in an *in vitro* fermentation model									
Treatment			**High-forage ration**				**High-grain ration**		
N-source	**[1]N-level**	**0 h**	**3h**	**9 h**	**12 h**	**0 h**	**3h**	**9 h**	**12 h**
Control	-	3.37 (±0.00)	9.29 (±1.79)[bc]	2.71 (±1.19)[c]	0.47 (±0.12)[c]	5.00 (±0.00)	5.64 (±0.83)[cd]	2.40 (±1.26)[b]	0.53 (±0.12)
SBM	Low	3.37 (±0.00)	8.95 (±1.89)[c]	1.93 (±1.17)[c]	0.99 (±0.24)[bc]	5.00 (±0.00)	6.45 (±1.08)[cd]	3.42 (±0.96)[b]	0.99 (±0.24)
SBM	Medium	3.37 (±0.00)	8.96 (±1.74)[c]	4.38 (±2.05)[c]	0.81 (±0.21)[bc]	5.00 (±0.00)	3.68 (±0.23)[d]	1.13 (±0.56)[b]	0.27 (±0.11)
SBM	High	3.37 (±0.00)	7.89 (±0.67)[c]	3.41 (±1.07)[c]	0.71 (±0.18)[bc]	5.00 (±0.00)	3.86 (±0.20)[d]	2.07 (±0.59)[b]	0.33 (±0.10)
SRU	Low	3.37 (±0.00)	9.25 (±1.86)[c]	4.64 (±2.11)[c]	0.70 (±0.19)[bc]	5.00 (±0.00)	9.29 (±1.00)[bcd]	2.75 (±1.41)[b]	0.35 (±0.13)
SRU	Medium	3.37 (±0.00)	12.85 (±2.01)[abc]	4.44 (±2.04)[c]	0.78 (±0.22)[bc]	5.00 (±0.00)	10.44 (±2.07)[bc]	2.49 (±0.91)[b]	0.53 (±0.20)
SRU	High	3.37 (±0.00)	10.34 (±2.82)[abc]	3.09 (±1.80)[c]	0.75 (±0.24)[bc]	5.00 (±0.00)	13.37 (±2.54)[b]	3.87 (±0.66)[b]	0.47 (±0.11)
Urea	Low	3.37 (±0.00)	11.94 (±2.05)[abc]	4.95 (±1.58)[c]	0.73 (±0.30)[bc]	5.00 (±0.00)	11.71 (±1.70)[bc]	3.97 (±1.21)[b]	0.48 (±0.15)
Urea	Medium	3.37 (±0.00)	18.91 (±1.94)[ab]	12.54 (±1.16)[b]	1.64 (±0.17)[b]	5.00 (±0.00)	22.38 (±0.96)[a]	4.70 (±1.44)[b]	0.88 (±0.22)
Urea	High	3.37 (±0.00)	19.59 (±2.35)[a]	22.73 (±0.92)[a]	3.16 (±0.15)[a]	5.00 (±0.00)	25.80 (±1.32)[a]	10.81 (±2.32)[a]	0.93 (±0.29)

[a–d] Different letters within same column are significantly different ($P < 0.05$).

N: nitrogen; SBM: soybean meal; SRU: slow-release urea

[1]N-level: low, medium and high nitrogen levels correspond to 1.07 mg N, 3.22 mg N and 5.35 mg N, respectively.

Table S14. Lactate concentration (mM) measured in an *in vitro* fermentation model							
Treatment		**High-forage ration**			**High-grain ration**		
N-source	**1N-level**	**0 h**	**9 h**	**12 h**	**0 h**	**9 h**	**12 h**
Control	-	5.85 (±0.73)	28.53 (0.61)[a]	0.80 (0.27)	4.23 (0.33)	34.89 (1.38)[c]	19.23 (2.11)[c]
SBM	Low	5.85 (±0.73)	26.96 (0.43)[ab]	0.44 (0.05)	4.23 (0.33)	35.20 (1.33)[c]	19.55 (1.01)[c]
SBM	Medium	5.85 (±0.73)	26.92 (0.94)[ab]	0.87 (0.29)	4.23 (0.33)	35.15 (0.70)[c]	18.84 (1.27)[c]
SBM	High	5.85 (±0.73)	24.54 (0.92)[b]	0.40 (0.06)	4.23 (0.33)	34.88 (0.60)[c]	18.38 (1.26)[c]
SRU	Low	5.85 (0.73)	26.76 (0.39)[ab]	0.72 (0.15)	4.23 (0.33)	43.58 (3.32)[bc]	27.07 (2.79)[bc]
SRU	Medium	5.85 (0.73)	26.09 (1.16)[ab]	0.54 (0.11)	4.23 (0.33)	45.05 (2.79)[bc]	27.47 (3.67)[bc]
SRU	High	5.85 (0.73)	26.84 (0.67)[ab]	0.49 (0.10)	4.23 (0.33)	48.47 (3.84)[ab]	34.51 (4.93)[ab]
Urea	Low	5.85 (0.73)	28.09 (0.96)[ab]	0.56 (0.11)	4.23 (0.33)	44.71 (1.16)[bc]	28.16 (1.53)[bc]
Urea	Medium	5.85 (0.73)	29.20 (1.15)[a]	0.80 (0.17)	4.23 (0.33)	57.17 (2.02)[a]	40.94 (2.63)[a]
Urea	High	5.85 (0.73)	27.21 (0.59)[ab]	0.80 (0.11)	4.23 (0.33)	58.24 (2.39)[a]	41.32 (2.49)[a]

[a–c] Different letters within same column are significantly different ($P < 0.05$).

N: nitrogen; SBM: soybean meal; SRU: slow-release urea

1N-level: low, medium and high nitrogen levels correspond to 1.07 mg N, 3.22 mg N and 5.35 mg N, respectively.

Table S15. Total volatile fatty acids concentration (mM) measured in an *in vitro* fermentation model

Treatment		High-forage ration			High-grain ration		
N-source	1N-level	0 h	9 h	12 h	0 h	9 h	12 h
Control	-	7.61 (±0.31)	57.97 (±1.62)	90.24 (±2.74)	7.40 (±0.17)	52.43 (±1.93)	82.65 (±0.75)
SBM	Low	7.61 (±0.31)	57.38 (±0.21)	91.51 (±0.88)	7.40 (±0.17)	52.00 (±0.95)	83.59 (±0.67)
SBM	Medium	7.61 (±0.31)	58.66 (±0.70)	89.62 (±1.38)	7.40 (±0.17)	50.79 (±0.36)	82.88 (±0.85)
SBM	High	7.61 (±0.31)	58.83 (±0.75)	91.16 (±0.63)	7.40 (±0.17)	51.84 (±0.37)	85.69 (±0.52)
SRU	Low	7.61 (±0.31)	56.27 (±0.73)	90.14 (±0.66)	7.40 (±0.17)	52.87 (±2.09)	83.77 (±0.93)
SRU	Medium	7.61 (±0.31)	59.12 (±2.27)	92.64 (±0.64)	7.40 (±0.17)	55.02 (±1.38)	84.04 (±0.82)
SRU	High	7.61 (±0.31)	56.36 (±0.48)	89.92 (±0.95)	7.40 (±0.17)	54.10 (±1.40)	82.96 (±1.20)
Urea	Low	7.61 (±0.31)	60.01 (±1.80)	92.08 (±0.68)	7.40 (±0.17)	52.85 (±0.30)	83.70 (±0.96)
Urea	Medium	7.61 (±0.31)	58.58 (±0.84)	90.94 (±1.13)	7.40 (±0.17)	54.68 (±0.68)	84.60 (±1.59)
Urea	High	7.61 (±0.31)	58.07 (±0.67)	90.52 (±0.96)	7.40 (±0.17)	55.37 (±1.20)	85.62 (±0.94)

Statistically significant differences were not observed within the same column.

N: nitrogen; SBM: soybean meal; SRU: slow-release urea

1N-level: low, medium and high nitrogen levels correspond to 1.07 mg N, 3.22 mg N and 5.35 mg N, respectively.