

Effects of protein and/or amino-acid levels on reproductive performance and metabolic profile of lactating sows

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(Received 4 December 1992; accepted 3 August 1993)

Summary — Three groups of 12 sows (high-productivity Goland hybrids) were fed from the 106th day of gestation to the end of lactation (27 ± 3 d) one of 3 diets: C₁, LP₁, LPS₁ (experiment 1). The diets differed in protein levels (CP (%DM): 16.7; 13.4; 14.1, respectively) and amino-acid content (lysine (%DM): 0.87; 0.48; 0.86; methionine + cystine (%DM): 0.57; 0.42; 0.56; threonine (%DM): 0.70; 0.53; 0.53; tryptophan (%DM): 0.20; 0.12; 0.20). In a second experiment, 4 groups of 11 sows were fed one of 4 diets (experiment 2): C₂, LP₂, LPPS, LPS₂ (CP (%DM): 17.2; 11.9; 13.3; 13.6, respectively; lysine (%DM): 0.77; 0.39; 0.54; 0.76; methionine + cystine (%DM): 0.59; 0.45; 0.52; 0.55; threonine (%DM): 0.67; 0.45; 0.56; 0.66; tryptophan (%DM): 0.20; 0.12; 0.17; 0.20, respectively). The LPS₁ diet was supplemented with the synthetic amino acids, lysine, methionine, tryptophan, and LPPS and LPS₂ were also supplemented with threonine. The different diets had no significant effects on sow performance and litter productivity. Low-protein and amino-acid-supplemented diets significantly reduced both blood (experiment 1: C₁ 30.3; LP₁ 28.0; LPS₁ 22.1 mg/dl; experiment 2: C₂ 36.5; LP₂ 31.4; LPPS 30.8; LPS₂ 21.3 mg/dl) and milk urea values (experiment 2: C₂ 20; LP₂ 13; LPPS 9; LPS₂ 10 mg/dl), which indicates a reduction in protein catabolism.

sow / dietary protein / amino acid / blood / milk

Résumé — Réalisation de 2 expériences pour vérifier la possibilité de réduire la teneur en protéines chez la truie en lactation. Dans la première expérience, 3 groupes de 12 truies (hybrides Goland fortes productrices) ont été alimentées avec des régimes qui avaient des taux de protéines (MAT % MS : C₁ 16,7 ; LP₁ 13,4 ; LPS₁ 14,1) et d'acides aminés différents (lysine % MS : C₁ 0,87 ; LP₁ 0,48 ; LPS₁ 0,86 ; méthionine + cystine % MS : C₁ 0,57 ; LP₁ 0,42 ; LPS₁ 0,56 ; thréonine % MS : C₁ 0,70 ; LP₁ 0,53 ; LPS₁ 0,53 ; tryptophane % MS : C₁ 0,20, LP₁ 0,12 ; LPS₁ 0,20) à partir du 106^e j de gestation jusqu'à la fin de la lactation (27 ± 3 j). Dans la deuxième expérience, 4 groupes de 11 truies recevaient 4 régimes expérimentaux (MAT % MS : C₂ 17,2 ; LP₂ 11,9 ; LPPS 13,3 ; LPS₂ 13,6 – lysine % MS : C₂ 0,77 ; LP₂ 0,39 ; LPPS 0,54 ; LPS₂ 0,76 méthionine + cystine % MS : C₂ 0,59 ; LP₂ 0,45 ; LPPS 0,52 ; LPS₂ 0,55 ; thréonine % MS : C₂ 0,67 ; LP₂ 0,45 ; LPPS 0,56 ; LPS₂ 0,66 ; tryptophane % MS : C₂ 0,20 ; LP₂ 0,12, LPPS 0,17 ; LPS₂ 0,20). Les régimes LPS₁, LPPS et LPS₂ étaient supplémentés à l'aide d'acides aminés

industriels. Pendant les 2 cycles reproductifs suivants, on a évalué les performances reproductives de la truie et productives des porcelets, le profil métabolique de la truie ; dans la deuxième expérience, on a évalué la composition du lait produit. Les régimes administrés n'ont pas entraîné des variations significatives des performances reproductives de la truie et productives des porcelets, qui ont maintenu de bons niveaux (1,1 insémination par gestation ; 2000 g/j de croissance de la portée). De plus, la réduction du taux des protéines et la supplémentation en acides aminés ont procuré un abaissement de la teneur en urée dans le sang (1^{re} expérience : C₁ 30,3 ; LP₁ 28 ; LPS₁ 22,1 mg/dl – 2^e expérience C₂ 36,5 ; LP₂ 31,4 ; LPPS 30,8 ; LPS₂ 21,3 mg/dl) et dans le lait (2^e expérience C₂ 20 ; LP₂ 13 ; LPPS 9 ; LPS₂ 10 mg/dl), en raison d'une diminution du catabolisme des protéines. L'analyse du profil métabolique et de la composition du lait amène à considérer que les régimes à faible teneur en protéines et après supplémentation équilibrée en acides aminés améliorent l'état métabolique de la truie.

truie / protéine / acides aminés / sang / lait

INTRODUCTION

During the productive cycle of swine, the lactation period is characterized by very high nutrient requirements. The dietary protein level is of major importance in the sow's productive and reproductive performance (*ie* milk production and hence weight gain of litter, body condition, readiness to re-breed) (Mordenti and Sacchi, 1985; Duée and Henry, 1986; Dourmad *et al*, 1991). Studies of nitrogen requirements during lactation have mostly focused on total dietary protein levels (Greenhalgh *et al*, 1980; King and Dunkin, 1986; Brendemuhl *et al*, 1987), whereas studies of essential amino acids are fewer and mainly concentrate on lysine, which is generally considered the primary limiting amino acid (King, 1987; Zeman and Siske, 1987; Etienne *et al*, 1989; Dourmad *et al*, 1991). The amino-acid requirement levels are however being revised. Recent studies (Etienne *et al*, 1989; Whittemore, 1990; Dourmad *et al*, 1991) have demonstrated the need to adjust requirement levels to the improved productivity of sows today, with litters of 10–12 and maximum milk production of 10 kg/d compared with litters of 8–9 and maximum milk production of 4–6 kg/d of the sows used in earlier studies on amino-acid requirements.

Since essential amino acids are insufficient and not completely available in conven-

tional feeds, lactating sows, like other animals with high nutritive requirements (*ie* in the first phases of growth), are frequently administered excessive amounts of protein (Gatel *et al*, 1991; Parisini *et al*, 1991). This method is criticized because the excess protein is utilized metabolically for energetic purposes, and because of its impact on the environment. Concern is mainly focused on the nitrogen content of excretions, which is directly related to the quality and quantity of the feed given. Notably, the concentration of nitrogen in the faeces (which accounts for about 30% of excreted N) depends on the digestibility of protein and therefore of the feed, whereas urinary nitrogen excretion (70% of N) is determined by the adaptability of nitrogen intake to the animal's requirements (Dourmad *et al*, 1989; Piva and Morlacchini, 1990; Gatel *et al*, 1991). The present availability of the complete range of pure amino acids (industrial or synthetic) makes it possible to form the amino-acid profile of a diet by providing the correct amount of essential amino acids without increasing dietary protein.

Following the study of Etienne *et al* (1989) and Dourmad *et al* (1991), high-production sows were used in experiments to determine the possibility of reducing the nitrogen content in the diet of the lactating sow.

MATERIALS AND METHODS

Two successive trials on hybrid Goland sows were conducted on a commercial farm. During the research the animals were monitored for their reproductive performance on 2 parities, with a conventional replacement rate of about 25% of the subjects. On average, the sows in experiment 1 completed 1.9 ± 0.7 cycles and those in experiment 2 25.9 ± 1.5 cycles. During pregnancy 2.6–2.8 kg/d of a conventional diet (G) was provided, depending on body condition score. Experi-

mental diets started about 8 d before farrowing. The animals were fed *semi-ad libitum* which, according to Batterham (1974), improves the utilization of amino-acid supplements. During the first week after farrowing the feed allowance was gradually increased to 6 kg/d. The composition of diets is reported in table I. The crude protein and amino acids were analysed, and the digestible energy was calculated. The differences in the protein content of LPS₁, LPPS and LPS₂ not due to amino-acid supplements were attributed to the industrial mixing of feed.

Table I. Experimental diet composition.

Diet	G	Experiment 1			Experiment 2			
		C ₁	LP ₁	LPS ₁	C ₂	LP ₂	LPPS	LPS ₂
Cassava	5.0	15.0	20.0	20.0	—	—	—	—
Corn	34.0	12.7	18.2	18.2	21.0	31.0	31.0	31.0
Barley	21.0	10.0	10.0	10.0	14.5	16.5	16.5	16.5
Wheat	—	10.0	13.0	13.0	10.0	10.0	10.0	10.0
Corn gluten meal	—	10.0	10.0	10.0	10.0	10.0	10.0	10.0
Beet pulp	—	6.0	5.0	5.0	10.0	10.0	10.0	10.0
Soybean (solvent extract)	12.0	13.5	—	—	10.0	—	—	—
Wheat flour middlings	7.0	—	—	—	5.0	8.0	8.0	8.0
Molasses	3.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
Fullfat soybean	3.0	8.0	7.0	7.0	5.0	—	—	—
Alfalfa hay	10.0	3.0	5.0	5.0	—	—	—	—
Linseed meal	—	—	—	—	3.0	3.0	3.0	3.0
Animal fat	—	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Dicalcium phosphate	2.0	2.0	2.0	2.0	1.5	1.5	1.5	1.5
Calcium carbonate	2.0	0.8	0.8	0.8	1.0	1.0	1.0	1.0
Trace elements + vitamins *	1.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
L-Lysine-HCl **	—	—	—	0.37	—	—	0.15	0.35
DL-Methionine **	—	—	—	0.13	—	—	0.06	0.09
L-Threonine **	—	—	—	—	—	—	0.10	0.20
L-Tryptophan **	—	—	—	0.075	—	—	0.04	0.07
Chemical analysis (DM)								
Crude protein (%)	16.76	16.67	13.41	14.10	17.20	11.89	13.28	13.60
Lysine	0.80	0.87	0.48	0.86	0.77	0.39	0.54	0.76
Methionine + cystine	0.48	0.57	0.42	0.56	0.59	0.45	0.52	0.55
Threonine	0.66	0.70	0.53	0.53	0.67	0.45	0.56	0.66
Tryptophan	0.18	0.20	0.12	0.20	0.20	0.12	0.17	0.20
DE (kcal/kg)	3 360	3 526	3 496	3 496	3 636	3 672	3 674	3 674
DE/CP (kcal/g)	20	21	26	24	21	31	28	27
DE/Lysine (kcal/g)	420	405	728	407	472	942	680	483

* Supplementation per kg of diet: vitamin A 15 000 IU; vitamin D₃ 2 000 IU; vitamin B₁ 2 mg; vitamin B₂ 6 mg; vitamin B₆ 2 mg; vitamin B₁₂ 0.01 mg; biotin 0.1 mg; vitamin E 10 mg; vitamin K 3 mg; vitamin PP 30 mg; *o*-pantothenic acid 11.5 mg; choline 400 mg; Mn 51 mg; Zn 67.2 mg; Fe 80 mg; Cu 25 mg; I 1.7 mg; Co 2.16 mg; Se 0.1 mg. In experiment 2 feeds were supplemented with 1 kg / 100 kg bentonite (DM 89.54%) containing: total ash 96.01%, insoluble acid ash 75.51%. ** Added after mixing diets LP₁ and LP₂.

Experiment 1

The control group (C_1) was given conventional feed, the second (LP_1) a low-protein diet, and the third (LPS_1) a low-protein diet supplemented with lysine, methionine, and synthetic tryptophan to equal C_1 values. The following was recorded: (i) sow weight 8 d before farrowing and at weaning; (ii) intervals to next oestrus, conception and parturition; (iii) litter size at birth and weaning (27 ± 3 d), and mortality numbers and causes; (iv) piglet weight 2 d after birth and at weaning. The metabolic profiles of blood samples collected from the jugular vein in the morning before feeding, on the day after farrowing and at weaning were analysed. The following parameters were analysed with Biochemia kits: urea; total protein; albumin; cholesterol; triglyceride; total lipids; and the enzymes GOT (aspartate-aminotransferase), GPT (alanine-aminotransferase), GGT (γ -glutamyl transferase). Kinetic tests were carried out at 25°C. The broader application of this study was contrived to include variations of the parameters not directly linked to protein metabolism.

Experiment 2

Using the same methods as described above, 4 groups of 11 sows were given one of 4 diets: control feed (C_2), low-protein feed (LP_2), low-protein feed with intermediate amino-acid supplementation (LPPS), and low-protein feed supplemented with lysine, methionine, threonine and tryptophan to equal C_2 values (LPS_2) (table I).

In addition to the productivity parameters studied in experiment 1, the following points were analysed. The composition of milk obtained after parenteral injection of 30–40 IU oxytocin was analysed 2 d after farrowing and on the 12th and 25th d of lactation. The pH was determined on individual samples. Density, dry residue (lyophilization and successive drying), protein (Kjeldahl method), fat (Gerber method), and urea (enzyme-conductimetric analysis by Bun-Analyzer 2, Beckman) were measured on a pool of 2 or 3 samples. In addition to the 2 blood samples taken as in experiment 1, another was taken 8 d before farrowing to obtain reference values. NEFA (non-esterified fatty acid) analysis was also added to the tests reported above.

Data from the 2 experiments was interpreted separately by an analysis of variance, compa-

ring the averages with Student's *t*-test; the 'cycle' factor originally introduced was subsequently excluded for its failure to cause significant effects on the variability of the parameters examined. Milk composition was calculated by a factorial scheme of analysis of variance of 4 diets \times 3 lactation stages. The statistical analysis of litter size and mortality was made by the χ^2 -test.

RESULTS

Experiment 1

Sow performance is reported in table II, and did not vary with the different diets; weaning–oestrus and weaning–conception intervals were optimum in all groups.

Litter size and weight at weaning (table III) were lower in the LP_1 group, as well as at birth. Litter performance was unaffected by the low-protein diets and the weight gain was satisfactory (2 000 g/d).

The metabolic profile obtained from the blood samples collected at farrowing and weaning is reported in table IV. In the former, which was taken about 8 d after experimental feeding was started, total protein declined in the LP_1 group. In the samples taken at weaning, total protein was similar in the 3 groups, but albumin was notably lower ($P \leq 0.01$) in LP_1 sows (3.0 g/100 ml) than in the other 2 groups ($LPS_1 = 3.4$ and $C_1 = 3.3$ g/100 ml). Moreover, urea values were significantly lower ($P \leq 0.01$) in the amino-acid-supplemented group LPS_1 (22.1 mg/100 ml) than in C_1 (30.3 mg/100 ml) and LP_1 (28.0 mg/100 ml).

Experiment 2

During this experiment the stock farm was affected by a high rate of piglet mortality, caused by the presence of many old sows with problems in milk production.

Table II. Experiment 1: sow productive performance.

Diet	<i>C</i> ₁	<i>LP</i> ₁	<i>LPS</i> ₁	EMS ^a (DF)
No of subjects	22	23	23	—
Initial weight (kg)	241.7	229.5	238.3	—
Weight loss (%)	22.4	22.0	20.7	36.56 (65)
Weaning—oestrus interval (d)	5.3	5.0	5.7	12.59 (63)
Weaning—conception interval (d)	7.3	11.3	8.6	262.78 (62)
No of matings	1.1	1.2	1.1	0.34 (62)
Interpartum (d)	149.3	152.6	146.7	202.46 (61)

^a EMS = error mean square; DF = degrees of freedom.

Table III. Experiment 1: litter productive performance.

Diet	<i>C</i> ₁	<i>LP</i> ₁	<i>LPS</i> ₁	EMS ^a (DF = 65)
No of litters	22	23	23	—
No of born	11.1	10.2	11.2	4.64
No of born alive	10.7	9.8	10.6	4.19
Weight at 2 d (kg)	1.74	1.76	1.68	0.06
No of weaned	9.9 ^c	8.7 ^d	9.5 ^{cd}	2.64
Weight at weaning (kg)	77.4 ^c	65.3 ^d	73.7 ^{cd}	207.13
Weight gain (g/d)	223	221	228	1.67
Mortality				
Crushing (%)	5.2	6.7	9.9	94.65
Other causes ^b (%)	2.6	2.8	2.5	27.74

^a EMS = error mean square; DF = degrees of freedom; ^b pathologies and malformation; different letters on the same line indicate significant differences of $P \leq 0.05$.

The data on productive performance is summarized in table V. There were no statistically significant differences in reproductive parameters. Piglet performance (table VI) shows statistically significant differences only in weight 2 d after birth (higher in LPPS piglets). In regard to mortality by crushing, it seems correct to ascribe this to the causes mentioned above.

The composition of milk at different stages of lactation is represented in table VII. The protein level did not differ significantly. Variability was to a great extent absorbed by the effect of 'lactation stage' since, as expected, the time of collection causes significant differences for nearly all the parameters. The milk urea results were quite interesting. Compared with group *C*₂

Table IV. Experiment 1: variations in the metabolic profile.

<i>Diet</i>	<i>C</i> ₁	<i>LP</i> ₁	<i>LPS</i> ₁	<i>EMS</i> ^a (<i>DF</i> = 60)
Parturition				
Total protein (g/dl)	7.5 ^b	7.0 ^c	7.5 ^b	0.46
Urea (mg/dl)	26.7	24.2	23.6	34.78
GGT (U/l)	31.7 ^b	24.7 ^c	19.5 ^c	110.12
Triglycerides (mg/dl)	31.6 ^{bc}	28.6 ^c	38.5 ^b	165.12
Weaning				
Total protein (g/dl)	6.6	6.9	6.4	0.79
Albumin (g/dl)	3.3 ^d	3.0 ^e	3.4 ^d	0.20
Urea (mg/dl)	30.3 ^d	28.0 ^d	22.1 ^e	21.99
GGT (U/l)	30.7 ^d	23.3 ^e	20.5 ^e	87.58
Total lipids (mg/dl)	432 ^e	528 ^d	398 ^e	20 986.88
Cholesterol (mg/dl)	77.0 ^e	94.8 ^d	88.1 ^{de}	339.95

^a EMS = error mean square; DF = degrees of freedom; different letters on the same line indicate significant differences of ^{b,c} $p \leq 0.05$ or ^{d,e} $P \leq 0.01$.

Table V. Experiment 2: sow productive performance.

<i>Diet</i>	<i>C</i> ₂	<i>LP</i> ₂	<i>LPPS</i>	<i>LPS</i> ₂	<i>EMS</i> ^a (<i>DF</i>)
No of subjects	22	22	22	22	—
Initial weight (kg)	242.0	265.0	261.9	262.4	—
Weight loss (%)	14.1	17.8	17.2	16.4	37.37 (84)
Weaning—oestrus interval (d)	7.8	4.1	5.0	5.0	7.53 (76)
Weaning—conception interval (d)	15.1	5.0	5.9	9.5	77.64 (76)
No of matings	1.2	1.1	1.1	1.2	0.06 (76)
Interpartum (d)	158.1	148.1	148.4	151.2	82.89 (75)

^a EMS = error square mean; DF = degrees of freedom.

values (20 mg/100 ml), the level was lower in *LP*₂ sows (13 mg) and even more so in *LPPS* and *LPS*₂ sows (9 and 10 mg, respectively). In table VIII the metabolic profile is analysed and subdivided into pre-parturition, parturition and weaning. Given the absence of specific literature on the subject, the first test was carried out independently of the diet provided. Differences in

the protein pattern were only significant in the case of albumin, and were higher at parturition than at weaning. Parameters relative to the lipid pattern were influenced most at the time of collection. The total lipids and cholesterol levels rose from pre-parturition to weaning, whereas the increase of NEFA and the concurrent triglyceride decrease at parturition are explained by body fat mobi-

Table VI. Experiment 2: litter productive performance.

Diet	C_2	LP_2	$LPPS$	LPS_2	EMS ^a (DF = 84)
No of litters	22	22	22	22	—
No of born	12.2	11.5	12.4	11.6	4.13
No of born alive	11.1	10.6	11.3	10.6	4.40
Weight at 2 d (kg)	1.42 ^d	1.44 ^d	1.60 ^c	1.43 ^d	0.05
No of weaned	9.4	9.3	9.3	8.9	2.76
Litter weight at weaning (kg)	66.4	65.2	63.3	64.9	123.94
Weight gain (g/d)	206	209	197	219	815.74
Mortality					
Crushing (%)	11.5 ^{cd}	7.2 ^c	12.9 ^d	8.1 ^{cd}	80.23
Other causes ^b (%)	3.6	6.0	5.2	5.9	61.13

^a EMS = error mean square; DF = degrees of freedom; ^b pathologies and malformations; different letters on the same line indicate significant differences of $P \leq 0.05$.

Table VII. Experiment 2: milk composition.

Factor	Diet				Lactation stage			EMS ^a (DF)
	C_2	LP_2	$LPPS$	LPS_2	Parturition	12th d	25th d	
pH	6.90 ^b	6.82 ^{bc}	6.73 ^c	6.88 ^c	6.42 ^c	7.03 ^b	7.05 ^b	0.05 (258)
Density (g/l)	1.033 ^e	1.035 ^d	1.033 ^e	1.033 ^e	1.036 ^b	1.031 ^c	1.033 ^c	0.00 (122)
Dry residue (%)	20.00	19.06	19.84	19.65	21.66 ^b	18.70 ^c	18.44 ^c	2.86 (107)
Fat (%)	8.48	7.58	8.09	9.08	8.55	8.08	8.14	4.64 (107)
Protein (%)	6.06	6.63	6.64	5.81	8.79 ^b	4.84 ^c	5.04 ^c	1.93 (107)
Urea (mg/100 ml)	20 ^b	13 ^c	9 ^f	10 ^{cd}	12	13	13	19.79 (55)

^a EMS = error mean square; DF = degrees of freedom. Different letters on the same line indicate significant differences of ^{b,c,f} $P \leq 0.01$ and ^{d,e} $p \leq 0.05$.

lization due to higher energy requirements at the beginning of lactation. Among the enzyme pattern values, plasma GOT levels increased at parturition.

In table IX, the data is analysed as a function of the different experimental feeds, and subdivided between parturition and weaning. There were significant differences in the protein pattern at parturition in the albumin

levels, which were decreased in LPS_2 sows, and in the urea levels, which were already lower in all low-protein groups, especially those supplemented with amino acids ($LPPS$ and LPS_2). All the parameters in the protein pattern varied at the end of lactation, and especially in the group LPS_2 , where protein and albumin approached C_2 levels and urea was the lowest of all the experimental groups.

Table VIII. Metabolic profile at different stages (data from experiment 2).

	<i>Preparturition</i>	<i>Parturition</i>	<i>Weaning</i>	<i>EMS</i> ^a (<i>DF</i> = 260)
Total protein (g/dl)	7.9	7.8	8.0	0.526
Albumin (g/dl)	3.3 ^{cd}	3.4 ^c	3.2 ^d	0.24
Urea (mg/dl)	29.1	27.9	29.9	62.95
GGT (U/l)	18.0	18.6	18.6	47.35
GOT (U/l)	13.7 ^d	24.1 ^c	14.7 ^d	40.49
GPT (U/l)	16.4	15.6	17.1	20.19
Total lipids (mg/dl) ^b	482 ^d	405 ^e	601 ^c	0.10
Triglyceride (mg/dl) ^b	73.9 ^{cf}	30.9 ^{dh}	50.6 ^{dg}	0.39
Cholesterol (mg/dl)	56.2 ^d	54.5 ^d	80.4 ^c	195.84
NEFA (μ Eq/l) ^b	169 ^{cdg}	235 ^{cf}	166 ^{dh}	0.33

^a EMS = error mean square; DF = degrees of freedom; ^b calculation made on values transformed into ln; different letters on the same line indicate significant differences of ^{cd}e $P \leq 0.01$ or ^{fg}h $P \leq 0.05$.

Table IX. Experiment 2: metabolic profile variations.

	<i>C</i> ₂	<i>LP</i> ₂	<i>LPPS</i>	<i>LPS</i> ₂	<i>EMS</i> ^a (<i>DF</i> = 81)
Parturition					
Total protein (g/dl)	7.8	7.6	7.9	7.9	0.49
Albumin (g/dl)	3.5 ^c	3.4 ^c	3.6 ^c	3.0 ^d	0.22
Urea (mg/dl)	36.5 ^c	29.7 ^d	23.5 ^e	22.5 ^e	62.33
GGT (U/l)	16.2 ^d	18.3 ^{cd}	17.9 ^{cd}	21.9 ^c	50.90
GPT (U/l)	13.4 ^{dg}	17.7 ^{cf}	15.7 ^{dfg}	15.3 ^{dgh}	12.41
Total lipids (mg/dl) ^b	333 ^d	398 ^d	496 ^c	384 ^d	0.11
NEFA (μ Eq/l) ^b	223 ^{cdf}	163 ^{dg}	256 ^{cdf}	297 ^{cf}	0.40
Weaning					
Total protein (g/dl)	8.0 ^{cdfg}	7.7 ^{dg}	7.9 ^{cdg}	8.4 ^{cf}	0.62
Albumin (g/dl)	3.3 ^{cf}	3.1 ^{dg}	2.8 ^{dh}	3.5 ^{cf}	0.17
Urea (mg/dl)	36.5 ^c	31.4 ^d	30.8 ^d	21.3 ^e	37.03
GOT (U/l)	13.0 ^d	14.6 ^d	17.8 ^c	13.0 ^d	10.22
GPT (U/l)	15.2 ^{dg}	18.2 ^{cdf}	19.2 ^{cf}	15.6 ^{dg}	17.33
Triglyceride (mg/dl) ^b	43.1	40.7	64.1	53.3	0.58
NEFA (μ Eq/l) ^b	161 ^{cdg}	119 ^{dg}	118 ^{dg}	304 ^{cf}	0.33

^a EMS = error mean square; DF = degrees of freedom; ^b calculation made on values transformed into ln; different letters on the same line indicate significant differences of ^{cd}e $P \leq 0.01$ or ^{fg}h $P \leq 0.05$.

Lipid data shows increased NEFA values in *LPS*₂ sows from parturition and especially at weaning. Finally, the values enzyme analysis at parturition increased in all experimental

groups, whereas at the end of lactation the GGT and GPT values were similar in *C*₂ and *LPS*₂ sows, and lower than those of the other 2 groups.

DISCUSSION

In verifying the balance of amino-acid supplements, ileal digestibility was presumed to be 90%, as proposed by Speer (cited by Dourmad *et al*, 1991). While in experiment 1 the supplement of lysine, and the methionine + cystine/lysine and threonine/lysine ratios were higher than those reported by Etienne *et al* (1989) and Dourmad *et al* (1991), in experiment 2 both lysine supplements and the amino-acid balance of diets C₂ and LPS₂ corresponded to the levels recommended by those authors. Diets LP₁, LP₂ and LPPS were unbalanced in the amino acids provided due to the elimination of soybean (solvent extract and full-fat) which reduced the lysine level.

In both experiments sow and litter performances were uninfluenced by the low-protein diets and remained on very satisfactory levels (matings about 1.1; litter weight gain exceeding 2 000 g/d). In group C₂ the weaning-conception interval and inter-parturition were longer due to the presence of a sow with serious reproductive problems. The greater weight of LPPS piglets at 2 d is hardly attributable to the experimental diet, which had been administered for only 8 d. Other researchers (Greenhalgh *et al*, 1980; King and Dunkin, 1986; Brendemuhl *et al*, 1987) observed decreased performance following dietary protein reduction, while in other trials (Zeman and Siske, 1987; Etienne *et al*, 1989) lysine supplements sustained them.

In the analysis of milk composition, the most notable aspect was urea, confirmed as reflecting the quality of dietary protein and amino-acid content to the animal's requirements. Unlike other researchers (Greenhalgh *et al*, 1980), a decreased in milk protein content after drastic dietary protein reduction with amino-acid supplements was not observed. The pH differences between the 4 groups are explained as in cows' milk (Bertoni, 1986) by the fact that the more

acidic samples (LPPS and LP₂) also have higher protein levels.

Finally, the metabolic profile has provided interesting results which are similar in the 2 experiments. In the protein analysis, urea and albumin behaved in a remarkable way. Albumin tended to decrease at weaning, though moderately and without reaching deficient values, and only in low-protein and low-amino-acid sows (LP₁, LP₂ and LPPS); it should be stressed that albumin, a transport serum protein, is synthesized in the liver depending on dietary amino-acid balance (Payne and Payne, 1987). The reduction of urea, which is widely considered to be inversely related to the biological value of dietary protein (Eggum, 1970; Malmlof and Askbrand, 1988), is an immediate indicator of nitrogen dietary decrease. This confirms the role of urea in reflecting the quality of dietary protein. The nitrogen values obtained in the 2 experiments, borne out by milk composition, indicate that these low-protein and low-amino-acid diets meet the lactating sow's metabolic requirements.

The results for the enzymes considered gave less precise indications, although it is to be emphasized that transaminase activity also makes up for the deficiency in non-essential amino acids. This may have occurred in experiment 2, where the LP₂ diet reached such low levels that it was insufficient in undifferentiated nitrogen, as already hypothesized by Etienne *et al* (1989) and Henry (1980). This explains the high GPT values of the LP₂ and LPPS groups and the total amino-acid supplement values being close to C₂ data. The increase in GOT at parturition can be correlated with this function.

The higher energy values observed in LP₁ sows at weaning can be attributed to the higher energy: AA ratio of this diet.

The most important results from the energy profile came from the analysis of triglycerides and NEFA, which are reliable

indicators of the energy utilization of diets. As noted above, the higher NEFA values observed in the LPS₂ group at the end of lactation could be due to the lipomobilization necessary to sustain high milk production, which is made possible in hybrid sows by adequate amino-acid dietary levels.

Overall, the results obtained in these experiments indicate that the levels of undifferentiated protein currently fed to lactating sows (15–17% as fed) can be substantially reduced to the levels tested in the present study. The small negative variations recorded with the LP₂ diet (crude protein 11.89% DM) suggest that the optimum undifferentiated protein level could be around 12.5% DM, with the addition of essential amino acids which have higher bioavailability than those contained in the usual protein sources. The absence of negative influences on sow and litter performances, and the improvement in the sow's metabolic condition (lower milk and blood urea) when the low-protein diet was partially or totally supplemented with amino acids, suggest that the intermediate levels (LPPS) of essential amino acids are sufficient. Despite the adverse opinion of Etienne *et al* (1989) regarding high-productivity sows, and the levels of lysine recommended by INRA 1989, this position seems to be supported by the fact that in the present experiments about 50% of the amino acids provided were synthetic.

ACKNOWLEDGMENTS

The authors gratefully acknowledge A Mordenti (University of Bologna) for critical evaluation of the manuscript and S Modena for editorial assistance. We thank G Levan and F Levan for assistance and availability on the pig farm. This research was carried out with contributions from the Italian Ministry of University and Scientific and Technological Research (MURST 60%) and CRPA of Reggio Emilia (Italy).

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