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The Economics of Quality Protein Maize as an Animal Feed: Case Studies of Brazil and El Salvador

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C · I · M · M · Y · T

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Abstract. This study examines the potential of quality protein maize (QPM) as an animal feed ingredient in Brazil and El Salvador. The minimum ingredient cost of pig and chicken feed with and without QPM and the optimal level of the main ingredients in the rations are obtained using linear programming models and compared for both cases. Sensitivity analysis is performed on relative prices of soybean meal (the main protein source), regular maize and sorghum (the main energy sources), synthetic lysine (the main amino acid supplement), and QPM. Model results indicate that QPM has the potential to reduce the production cost of pig feed by as much as 5.0% in Brazil and 3.4% in El Salvador. Chicken feed cost savings of QPM are as high as 2.9% in Brazil and 2.8% in El Salvador. If assigned the same price as regular maize, QPM constitutes 80% of the optimal pig feed in Brazil, replacing all regular maize and synthetic lysine and 40% of the soybean meal. At a 5% price premium over regular maize, QPM constitutes 50% of the optimal pig diet. In El Salvador, QPM priced the same as regular maize also forms 80% of the pig diet; at a 5% price premium, QPM constitutes 40% of the diet. In both countries savings at the industry level depend on the size and technological sophistication of the pig industry and on the prices of the feed ingredients with which QPM competes. Future research and agricultural policy should emphasize means of distinguishing QPM from regular maize, improvement of QPM's storability, and promotion of QPM varieties already available.

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Introduction

Quality protein maize (QPM) is a nutritionally superior cereal grain that possesses a higher proportion of two key amino acids, lysine and tryptophan, than is found in regular maize. Because of its higher quality protein, QPM has been seen as a promising solution to the protein deficit in regions where maize is an important staple food, such as many parts of Africa, some countries in Asia, Mexico, and Central America, and the Andean highlands. However, QPM's nutritional superiority in the diets of malnourished people in developing countries is still unclear, for nutritionists have not yet agreed on the relative importance of energy versus protein in such diets (see for example Hegsted 1978, UNU 1979, Tripp 1990).

On the other hand, QPM has amply demonstrated its superior performance as feed for monogastric animals, especially pigs and chickens. For example, chickens and pigs convert QPM feed into weight gain more efficiently than regular maize feed (e.g., Jarkin, Albertazzi, and Bressani, 1970; Maner 1975; Asche et al. 1985). Thanks to its higher protein quality, QPM may also prove important as a substitute for some of the protein sources commonly used in animal feeds, such as soybean meal and synthetic amino acids, which are more expensive than maize.

Maize and sorghum are the main energy sources in feed rations for pigs and chickens in many countries. The main source of protein is usually soybean meal. Countries producing enough of these ingredients to meet domestic demand are few, and thus one or both kinds of ingredient usually must be imported. Therefore it is important to determine if QPM, with its higher protein quality, can substitute for regular maize and/or sorghum as a more efficient energy source and, at the same time, for soybean meal and/or synthetic amino acids as a protein source in feed rations.

Although there is little doubt that QPM performs better in feed than other energy sources such as maize and sorghum, few studies have analyzed the potential cost and feed composition effects of adding QPM to animal rations (see for example Pinstrup-Andersen, 1982, and Sain, Nuila, and Pereyra, 1991). If QPM is an economically feasible alternative to regular maize as well as to soybean meal and other protein sources in pig and chicken feed, substantial benefits may be achieved in the form of greater efficiency of feed rations and potentially lower imports of protein sources for feed.

This study examines the economics of using QPM in feed rations through case studies in Brazil and El Salvador. The study seeks to answer one main question: Can QPM substitute for regular maize, sorghum, and/or soybean meal and other protein sources in pig and poultry feed in an economically efficient manner, reducing total costs of production enough to provide incentives for the feed industries in Brazil and El Salvador to use QPM? The basis for determining the potential of QPM in pig and poultry diets will be the total ingredient costs of feed production. The nutritional characteristics of regular maize, QPM, soybean meal, and other cereals and ingredients will be considered to estimate the minimum cost at which feed rations for the different growth stages of poultry and pigs can be produced.

The two countries selected for the study provide an opportunity to estimate the potential benefits of QPM in different settings. In addition to the differences in area and potential feed markets in the two countries, Brazil has large and sophisticated pig and poultry industries, whereas in El Salvador these industries are still developing and much smaller. In contrast to Brazil, where most feed ingredients except synthetic lysine are produced domestically, El Salvador imports many feed ingredients, especially soybean meal, synthetic lysine, and yellow maize. Sorghum is an important domestically produced source of energy for feed rations in El Salvador, whereas maize is the main energy source in Brazil. However, one important characteristic shared by Brazil and El Salvador is that both countries have relatively sophisticated maize seed industries, an important factor in the development of commercial seed of QPM.

Before the issue of QPM's potential in animal feed is addressed, brief summaries of the development of QPM and trends in maize and feed production in El Salvador and Brazil will be useful. This information is presented in the sections that follow.

The Development of Quality Protein Maize

Quality protein maize was developed by plant breeders at CIMMYT through genetic improvement to take advantage of the Opaque-2 gene discovered in maize at Purdue University in 1963 (NRC 1988a). The main nutritional differences between regular maize and QPM are shown in Table 1. As can be seen, the quantity of energy and protein in QPM is no different from that of regular maize, although some studies have shown QPM to have a higher energy and protein content compared to regular maize (Rostango et al. 1988, Peixoto et al. 1990). The proportion of lysine and tryptophan is substantially higher in QPM than in regular maize, however (approximately 75% for lysine and 83% for tryptophan). The leucine-to-isoleucine ratio also differs in the two types of maize. The lower leucine-to-isoleucine ratio in QPM is believed to promote more efficient use of the total protein in QPM by humans and monogastric animals. Therefore, the two types of maize differ mainly in protein quality, not quantity, and this quality difference is the basis for the analysis presented below.

The problems that plagued earlier Opaque-2 maize varieties have largely been resolved in the new QPM cultivars, especially grain yield. Yields of current QPM cultivars are identical to those of the best improved regular maize hybrids (CIMMYT 1985, Bjarnason 1991). Plant breeders in several countries have developed new QPM cultivars adapted to local environments, notably the varieties Nutricta in Guatemala, Nutri-Guarani in

Paraguay, and more recently BR-451, developed by scientists at the Brazilian National Center for Maize and Sorghum Research (CNPMS). The variety BR-451 was released and promoted in 1988 through a massive campaign that was unprecedented in Brazil for such a product.

The problems that remain in QPM are related mostly to maintaining seed quality. Since the Opaque-2 gene that confers the higher protein content is recessive, it is easily lost through intermixing in maize fields. This implies that to preserve the protein quality of QPM varieties and hybrids, fresh seed has to be purchased every crop cycle. Another problem is the difficulty of physically appreciating QPM's higher protein quality. The lack of a physical difference between QPM and regular maize has hindered extension efforts to promote QPM varieties, as potential adopters cannot distinguish them from regular maize. Until recently, fairly complicated chemical tests were necessary to identify the levels and proportions of amino acids that set high quality protein maize and regular maize apart. However, some simple techniques have been developed to determine if a given maize is QPM (Bjarnason and Vasal 1992). The identification problem could also be solved by releasing QPM cultivars with colors different from those of regular maize in a given region or country. For example, the new QPM variety developed in Brazil is white, whereas virtually all the regular maize produced is yellow.

Table 1. Nutrient composition of regular maize and quality protein maize

Nutrient	Units	Regular maize	QPM
Metabolizable energy (pigs)	Kcal/kg	3,430	3,430
Metabolizable energy (chickens)	Kcal/kg	3,480	3,480
Crude protein	%	9.70	9.70
Calcium	%	0.02	0.02
Digestible phosphorus	%	0.09	0.09
Methionine	%	0.15	0.16
Methionine + Cystine	%	0.30	0.34
Threonine	%	0.33	0.37
Arginine	%	0.39	0.56
Valine	%	0.43	0.46
Phenylalanine	%	0.45	0.40
Isoleucine	%	0.30	0.28
Leucine	%	1.14	0.85
Lysine	%	0.24	0.42
Tryptophan	%	0.06	0.11
Leucine/isoleucine ratio		3.80	3.04

Source: Unpublished data, Protein Quality Laboratory, CIMMYT.

Maize and Feed Production in El Salvador

Maize and sorghum are the main cereals produced in El Salvador. A high proportion of maize and sorghum is produced in mixed cropping systems. Farmers generally use improved varieties and low levels of purchased inputs, although some large-scale farmers use high levels of inputs and improved maize cultivars, almost entirely in monocrop systems. Sorghum is also produced by large-scale farmers exclusively for animal feed on the farm or for sale to the feed industry. Maize and sorghum yields in El Salvador are relatively high compared to those in the rest of Central America (Tables 2 and 3).

Table 2. Maize area, yield, production, and per capita production, El Salvador, 1980-90

Year	Area (000 ha)	Yield (kg/ha)	Production (000 t)	Production per capita (kg)
1980	292	1,815	529	117
1981	276	1,809	500	109
1982	239	1,734	414	90
1983	241	1,834	443	95
1984	243	2,166	527	112
1985	254	1,954	495	104
1986	257	1,678	432	89
1987	279	2,045	570	117
1988	282	2,086	588	117
1989	276	2,102	581	113
1990	282	2,189	616	117
Average annual growth rate	**0.6**	**1.9**	**2.5**	**1.0**

Source: FAO *Production Yearbook* (various issues).

Table 3. Sorghum area, yield, production, and per capita production, El Salvador, 1980-90

Year	Area (000 ha)	Yield (kg/ha)	Production (000 t)	Production per capita (kg)
1980	120	1,171	140	31
1981	115	1,176	136	30
1982	119	1,044	124	27
1983	111	1,113	123	26
1984	116	1,209	141	30
1985	114	1,159	133	28
1986	120	1,229	148	30
1987	125	207	26	5
1988	122	1,241	151	30
1989	120	1,233	148	29
1990	129	1,244	161	31
Average annual growth rate	**0.8**	**-2.1**	**-1.3**	**-2.8**

Source: FAO *Production Yearbook* (various issues).

The feed industry is small but growing fast, producing approximately 300,000 t of commercial feed in 1990. Maize and sorghum are the main sources of energy in commercial feed rations. Of the commercial feed produced in El Salvador, 78% is for poultry and only 8% for pigs; the remaining 14% is for cattle (Table 4). Approximately 15% of all the white maize produced in the country is used for animal feed either directly or through purchased feed rations, and all the yellow maize is used for commercial feed rations. The percentage of sorghum production used for feed is higher than the percentage of white maize production. Sorghum sales for animal feed reached a high of 62% in 1987 (Table 5). The main source of protein in the feed rations is soybean meal; less important sources are cottonseed meal and maize gluten meal (Table 6). All of these protein ingredients are imported, mainly from the United States.

Table 4. Animal feed production in El Salvador, 1980-90, and projections to 1995

Year	Feed for:				Percentage:	
	Poultry	Cattle	Swine	Total	Poultry	Swine
1980	169	11	2	182	93	1
1981	161	14	2	177	91	1
1982	165	16	2	183	90	1
1983	179	27	3	209	86	1
1984	199	26	4	230	87	2
1985	226	22	5	252	89	2
1986	236	25	9	270	87	4
1987	222	28	11	262	85	5
1988	224	32	15	272	83	6
1989	224	37	19	280	80	7
1990	232	42	24	298	78	8
Projections:						
1991	237	44	25	306	77	8
1992	242	46	27	315	77	9
1993	248	48	28	325	76	9
1994	253	50	30	334	76	9
1995	259	52	32	344	75	10
Average annual growth rate						
1980-90	**4.0**	**11.5**	**28.4**	**5.5**	**-1.5**	**22.9**
1990-95	**2.3**	**4.3**	**6.2**	**2.9**	**-0.6**	**3.2**

Source: AVES, Asociación de Avicultores de El Salvador. Projections based on the average growth rates for the 1985-90 period.

Table 5. Main cereals used in feed production, El Salvador, 1980-89

Year	Cereal(s) (000 t)				Percentage share of total production	
	White maize	Yellow maize	Sorghum	Total	White maize	Sorghum
1980	42	23	32	97	8	23
1981	40	26	22	88	8	17
1982	42	23	28	93	10	22
1983	5	73	27	105	1	22
1984	7	80	22	108	1	15
1985	53	20	54	127	11	41
1986	87	6	42	135	20	28
1987	53	50	16	119	9	62
1988	72	50	4	126	12	3
1989	33	48	41	122	6	28
Average annual growth rate	**8.3**	**3.7**	**-6.2**	**4.1**	**6.2**	**-2.6**

Source: MAG, Economía Agropecuaria; and AVES, No. 13.

Poultry and egg production increased substantially in El Salvador during the early 1980s, stabilized in the late 1980s, and has remained constant over the last several years (Table 7). Pork production during the 1980s remained stable after a steep drop early in the decade. Following substantial growth in the 1970s, beef production showed a steep decline in the mid-1980s. Meat and other animal products account for a small percentage of foreign trade in El Salvador (Table 8), and only beef and milk products showed any significant trade in the 1980s.

Table 6. Main protein sources (000 t) in feed, El Salvador, 1980-89

Year	Soybean meal	Cottonseed meal	Meat meal	Maize gluten	Total
1980	19.2	13.0	3.1	0.0	35.4
1981	24.5	13.6	1.2	1.2	40.4
1982	26.3	12.1	3.5	2.2	44.1
1983	26.6	9.5	7.0	3.0	46.2
1984	35.5	7.1	5.6	2.4	50.5
1985	43.7	3.6	5.3	5.8	58.4
1986	45.2	3.8	5.9	8.1	63.0
1987	46.5	0.1	2.3	5.0	53.9
1988	48.2	1.5	0.3	1.9	51.8
1989	45.4	4.6	0.2	3.5	53.8
Average annual growth rate	**10.4**	**-31.8**	**-21.9**	**42.5**	**4.6**

Source: MAG, Economía Agropecuaria; and AVES, No. 13.

Table 7. Meat, egg, and milk production (000 t), El Salvador, 1980-90

Year	Poultry	Pork	Beef	Eggs	Milk
1980	13	16	28	35	291
1981	13	13	30	30	293
1982	16	13	30	38	268
1983	16	13	30	35	249
1984	23	13	22	38	213
1985	25	13	21	41	290
1986	29	15	22	40	232
1987	29	15	19	42	251
1988	28	14	22	44	248
1989	36	14	28	49	259
1990	37	14	28	29	270
Average annual growth rate	**11.3**	**0.1**	**-2.0**	**1.0**	**-1.1**

Source: FAO *Production Yearbook* (various issues).

The demand for maize and sorghum for the feed industry and other uses in El Salvador increased substantially during the 1980s, resulting in a sharp increase in maize imports, especially yellow maize from the United States (Table 9). This situation, combined with increasing demand for wheat following on rapid urbanization, created a growing dependency in El Salvador on imports to meet domestic demand for these cereals. However, imports of yellow maize have released some of the pressure for white maize for feed. Growth in per capita production of the main cereal grains was positive for maize and negative for sorghum during 1980-90 (Tables 2 and 3). The gains in per capita maize production are the result of higher yields and low population growth rather than growth in maize area, which remained stable over the period.

Table 8. Net exports (t) of meat and other animal products, El Salvador, 1980-90

Year	Poultry	Pork	Beef	Eggs	Milk[a]
1980	-67	-263	1,684	292	-13,115
1981	-100	0	335	270	-12,503
1982	56	0	1,348	-135	-8,747
1983	106	0	1,645	90	-10,970
1984	-542	-18	1,079	170	-4,431
1985	57	0	1,015	410	-4,681
1986	-414	0	395	490	-3,985
1987	-205	-20	1,095	45	-9,677
1988	-206	-20	1,147	-25	-10,430
1989	-17	-99	1,292	-125	-6,469
1990	-5	0	872	-150	-7,657

a Fresh, condensed, evaporated, and dry milk.
Note: Negative numbers indicate net imports.
Source: FAO *Trade Yearbook* (various issues).

Table 9. Net imports (000 t) of cereals in El Salvador, 1980-90

Year	Maize	Wheat	Sorghum	Total
1980	-5.5	116.5	6.6	117.6
1981	-0.8	106.4	0.1	105.7
1982	26.4	135.7	0.1	162.2
1983	102.2	122.7	0.1	225.0
1984	86.5	148.0	0.0	234.5
1985	55.0	150.9	0.0	205.9
1986	24.3	169.6	0.0	193.9
1987	58.9	105.4	0.0	164.3
1988	37.7	105.2	1.0	143.9
1989	68.8	106.5	0.0	175.3
1990	61.0	104.9	0.0	165.9

Source: FAO *Trade Yearbook* (various issues). Negative numbers indicate net exports.

Maize and Feed Production in Brazil

Brazil is the world's third largest maize producer after the United States and China, producing over 21 million tons (MT) of maize in 1990 (Table 10). Sorghum is not as important in Brazil as in El Salvador, although total production grew in the 1980s as the area planted to sorghum expanded (Table 11). In 1985-87, 14% of Brazil's total maize

Table 10. Maize area, yield, production, and per capita production, Brazil, 1980-90

Year	Area (million ha)	Yield (kg/ha)	Production (million t)	Production per capita (kg)
1980	11.5	1,779	20.4	168
1981	11.5	1,836	21.1	170
1982	12.6	1,731	21.8	172
1983	10.7	1,745	18.7	144
1984	12.0	1,761	21.2	159
1985	11.8	1,866	22.0	162
1986	12.5	1,647	20.5	148
1987	13.5	1,984	26.8	189
1988	13.2	1,877	24.7	151
1989	12.9	2,058	26.6	180
1990	11.4	1,869	21.3	142
Average annual growth rate	**1.0**	**1.0**	**2.0**	**-0.2**

Source: FAO, *Production Yearbook* (various issues).

Table 11. Sorghum area, yield, production, and per capita production, Brazil, 1980-89

Year	Area (000 ha)	Yield (kg/ha)	Production (000 t)	Production per capita (kg)
1980	78	2,305	180	1.5
1981	92	2,308	212	1.7
1982	123	1,847	226	1.8
1983	112	1,947	217	1.8
1984	171	1,830	313	2.4
1985	163	1,583	258	2.0
1986	196	1,866	365	2.6
1987	239	1,898	453	3.1
1988	195	1,545	302	2.1
1989	161	1,464	236	1.6
1990	133	1,710	228	1.5
Average annual growth rate	**6.8**	**-3.3**	**3.5**	**1.4**

Source: FAO, *Production Yearbook* (various issues).

production was destined for direct human consumption, especially by small-scale farmers; 11% went for seed and other uses; and 75% went to the feed industry (CIMMYT 1990). Table 12 shows recent trends in net cereal imports in the country. Brazil is also an important producer and exporter of soybeans and soybean meal, the main protein source used in diets for pigs and poultry throughout the world (Table 13).

Table 12. Cereal imports (000 t), Brazil, 1980-89

Year	Maize	Wheat	Sorghum	Total
1980	1,588	4,758	0	6,346
1981	895	4,363	-11	5,247
1982	-543	4,223	-33	3,647
1983	-553	4,179	0	3,626
1984	75	4,868	-23	4,920
1985	262	4,037	-2	4,297
1986	2,423	2,253	0	4,676
1987	871	2,758	0	3,629
1988	258	939	0	1,197
1989	1,621	1,307	na	2,928
1990	6,992	2,216	na	9,208

Source: FAO *Trade Yearbook* (various issues).
Note: Negative numbers indicate net exports; na = not available.

Table 13. Soybean area and production and soybean meal production and exports, Brazil, 1980-90

Year	Soybean area (000 ha)	Soybean production (000 t)	Soybean meal production (000 t)	Soybean meal exports (000 t)
1980	8,774	15,156	9,968	8,562
1981	8,501	15,200	10,607	7,822
1982	8,136	14,750	9,960	7,994
1983	9,421	15,541	9,714	7,690
1984	10,153	18,278	10,688	8,628
1985	9,450	14,100	9,590	6,961
1986	9,270	17,300	10,782	8,030
1987	10,524	18,021	10,710	8,477
1988	12,170	23,200	12,625	9,577
1989	11,400	20,340	12,082	8,994
1990	9,650	15,500	10,140	7,400
Average annual growth rate	2.7	2.6	1.4	0.4

Source: USDA/FAS *World Oilseed Situation and Highlights,* FOP 7-88, July 1988; *World Oilseed Situation and Outlook,* FOP 1-92, January 1992.

Brazil's highly developed feed industry plays an important role in linking agricultural production, especially of maize and soybeans, with the food processing sector. A total of 14.8 MT of feed for different uses was produced in Brazil in 1990 compared to 11 MT in 1985, a 35% increase in five years (although 3.3% lower than the 1980 level of 15.3 MT) (Table 14). It is important to note that the relative importance of commercial feed for pigs and chickens is different in Brazil and El Salvador. On average, 67% of the feed in Brazil is for poultry, 27% for pigs, and 6% for cattle and other uses; the figures for El Salvador are 78% for poultry, 8% for pigs, and 14% for cattle. Whereas Brazil produced 3.8 MT of pig feed in 1990, El Salvador produced only 24,000 t.

Maize and maize products alone account for about 75% of the ingredients used in the Brazilian feed industry, indicating the importance of maize as a feed ingredient. Other important ingredients are soybean meal, wheat middlings, and meat meal. Mineral and protein supplements include calcium carbonate, dicalcium phosphate, and synthetic

Table 14. Animal feed production in Brazil, 1980-90, and projections to 1995

	Feed for:				Percentage:	
Year	Poultry	Cattle	Swine	Total	Poultry	Swine
1980	9,435	1,363	4,478	15,276	61.8	29.3
1981	8,739	1,288	4,054	14,081	62.1	28.8
1982	8,385	904	3,180	12,469	67.2	25.5
1983	7,759	889	2,750	11,398	68.1	24.1
1984	7,372	691	2,574	10,637	69.3	24.2
1985	7,567	718	2,724	11,009	68.7	24.7
1986	8,276	862	4,161	13,299	62.2	31.3
1987	9,413	929	4,133	14,475	65.0	28.6
1988	9,184	922	3,779	13,884	66.1	27.2
1989	9,275	830	3,631	13,736	67.5	26.4
1990	10,157	851	3,762	14,769	68.8	25.5
Projections						
1991	10,773	879	4,013	15,665	68.8	25.6
1992	11,426	910	4,281	16,617	68.8	25.8
1993	12,119	941	4,567	17,627	68.8	25.9
1994	12,854	972	4,871	18,697	68.8	26.1
1995	13,633	1,006	5,196	19,835	68.8	26.2
Average annual growth rate						
1980-90	**1.3**	**-3.4**	**0.5**	**0.7**	**0.6**	**-2.3**
1990-95	**5.9**	**3.4**	**6.5**	**5.9**	**0.0**	**0.6**

Note: Projections based on the average growth rates for 1985-90.
Source: Sindiracoes, Sao Paulo, Brazil.

amino acids such as lysine, methionine, and tryptophan. The average growth rate of maize use by the Brazilian feed industry was much higher than the average growth rate of maize production in the country between 1980 and 1990.

Total maize production has declined in recent years as a result of lower yields and total area harvested, because price policies have favored the production of export crops, especially soybeans. The result was negative per capita growth in maize production during the 1980s. If this trend is not reversed, total maize production will not cover Brazil's needs for feed grain, let alone maize for direct human consumption and other uses. Recent agricultural policy reforms are expected to provide incentives for maize production, although the area for expansion is limited and less productive than current maize area. Recent movements in the international prices of cereals, especially reductions in the wheat price and increases in the maize price, may also provide the necessary incentive to increase maize production in the country.

Table 15. Meat, egg, and milk production (000 t), Brazil, 1980-89

Year	Poultry	Pork	Beef	Eggs	Milk
1980	1,341	980	2,084	782	10,265
1981	1,416	980	2,110	830	10,500
1982	1,619	970	2,397	829	11,817
1983	1,680	950	2,360	785	11,818
1984	1,416	780	2,161	964	12,303
1985	1,549	770	2,223	1,000	12,580
1986	1,667	825	1,958	1,134	12,879
1987	1,854	990	2,262	1,250	13,399
1988	2,001	1,100	2,581	1,178	13,928
1989	2,146	1,000	2,748	1,189	13,815
1990	2,417	1,050	2,882	1,300	14,228
Average annual growth rate	**5.3**	**1.0**	**2.4**	**5.1**	**3.7**

Source: FAO *Production Yearbook* (various issues).

Table 16. Net exports (000 t) of meat and other animal products, Brazil, 1980-89

Year	Poultry	Pork	Beef	Eggs	Milk[a]
1980	170.4	0.0	-58.7	9.1	-61.0
1981	294.8	1.2	-13.7	12.1	-8.0
1982	296.8	2.6	73.8	4.8	-7.5
1983	290.4	2.3	97.0	0.4	-18.5
1984	281.2	6.3	80.9	1.2	-29.4
1985	279.3	4.6	91.6	1.1	-30.4
1986	235.8	-29.7	-361.6	0.3	-214.1
1987	215.7	-26.6	-77.3	0.8	-100.5
1988	245.7	19.0	149.2	0.3	-1.2
1989	246.5	-40.7	-104.9	0.4	-104.9
1990	303.0	9.9	-146.7	0.4	-50.8

a Fresh, dry, condensed, and evaporated milk.
Note: Negative numbers indicate net imports.
Source: FAO *Trade Yearbook* (various issues).

Production and trade of animal products for Brazil in the last decade are presented in Tables 15 and 16. Poultry, egg, and milk production showed the strongest growth during the 1980s, although pork production grew strongly in the last five years. Poultry and to a lesser extent beef meat are traditional Brazilian exports, although beef has shown relatively large trade deficits in the last few years. Brazil moved from being a net exporter to a net importer of pork in the 1980s, although the amounts traded were small, as they were for the egg trade.

Procedures and Data Sources

To estimate the economic potential of QPM as an ingredient for poultry and pig feed in Brazil and El Salvador, optimal feed rations with and without QPM were constructed for the different pig and chicken growth stages and for each country. The rations were formulated so that the nutritional value with and without QPM was the same and all energy, protein, and other nutritional requirements set by the industry were met. Minimum and maximum quantities of the different ingredients and levels of substitution between ingredients were also taken into account.

Linear programming (LP) models were developed in which the total ingredient cost of producing rations with and without QPM was minimized. The models were developed and run using GAMS (Brooke, Kendrick, and Meeraus 1988) and LINDO (Schrage 1987) software for personal computers. The objective function in the models was minimization of the ingredient cost of producing one ton of feed, subject to the nutritional content of each ingredient in the mix, the minimum and maximum nutritional requirements of the animal, and minimum and maximum percentages of the main ingredients. Mathematically, the model can be expressed as:

$$\text{Minimize:} \quad C = \Sigma_i P_i{*}X_i \qquad i = 1,2,\ldots,n \text{ ingredients}$$

$$\text{Subject to:} \quad B_j <= \Sigma_j N_{ij}X_i <= D_j \qquad j = 1,2,\ldots,m \text{ nutrients}$$

$$L_i <= X_i <= U_i,$$

$$\Sigma_i X_i = 100, \text{ and}$$

$$X_i >= 0,$$

where C is the total production cost of one ton of feed for a given growth stage of poultry or pigs in US dollars; P_i is the price in US$/kg of ingredient X_i; N_{ij} is nutrient j content in ingredient i (%); B_j and D_j are, respectively, the minimum and maximum requirements of nutrient j in the ration; and L_i and U_i are, respectively, the minimum and maximum levels of ingredient i allowable in the ration.

The data used for the analysis were the nutritional requirements for chickens and pigs at different growth stages, the nutritional content of the ingredients available in each country (Rostango et al. 1987, NRC 1984, NRC 1988b), and the prices of ingredients. The nutritional characteristics of regular maize and QPM used in the LP model are shown in Table 1. Note that the energy and protein content are assumed to be the same for both kinds of maize, and the main difference is in the lysine and tryptophan content.

Because of the difficulties of tracking real prices in countries with high inflation rates, a system of price ratios, using the international price of regular maize as the base, was used to express the prices of the main ingredients in the diets. For example, the prices of soybean meal and sorghum were assumed to be their long-term averages relative to the price of regular maize. The price of QPM initially was set equal to that of regular maize. This procedure facilitates interpretation of the results and provides an easy way to test the sensitivity of results to changes in relative prices. This system also allows for the model to be applied in any country, given the price of only one common ingredient (in this case the international price of regular maize adjusted for transportation costs) and estimates of the prices of other important ingredients relative to that base price. The prices of the main ingredients used in the base model (Table 17) are mostly international prices and were used in the base analysis for both countries. The sensitivity analysis compared the results with these price ratios to results of cases in which one or more of the price ratios were changed.

The LP model results include the minimum ingredient cost of producing one ton of feed, the optimal percentage of each ingredient in the ration, the range of ingredient prices over which the optimal mix remains unchanged, and the surplus or slack values for the different nutrient constraints. In addition, sensitivity analysis was performed on the prices of regular maize, QPM, soybean meal, sorghum, and synthetic lysine — the ingredients for which QPM potentially could substitute. In all cases, feed costs and levels of QPM in the diets were compared to obtain an estimate of the level of substitutability between QPM and other ingredients used by the industry and of the potential cost savings from using QPM in the feed diets.

The models for the two countries therefore differed primarily in the feed ingredients that were available domestically, the most important being sorghum, which is not used in Brazil but constitutes an important energy source in feed in El Salvador. Other differences can be seen in the GAMS programs showing the LP models for the first growth stage of pigs (Appendix A). Ingredient prices, nutritional requirements for different growth stages, and nutritional characteristics of the ingredients can also be seen in the GAMS programs.

Table 17. Prices (US$/t) of main ingredients used in the base linear programming model

Ingredient	Price
Regular maize	120
Quality protein maize	120
Sorghum	114
Soybean meal	240
Synthetic lysine	3,200
Synthetic methionine	3,250

Note: The prices for QPM, soybean meal, and sorghum are set such that the soybean meal-to-regular maize ratio = 2; the QPM-to-regular maize price ratio = 1; and the sorghum-to-regular maize price ratio = 0.95.

Source: For regular maize: UNCTAD, CNUCED *Monthly Commodity Price Bulletin*; for lysine and methionine: *Chemical Marketing Reporter*, Chemical Prices (various issues).

Results of the Base Model

Given the nutritional requirements of pigs and chickens, the greatest potential cost savings from using QPM is in the formulation of pig feed. Lysine is the first limiting amino acid in maize-based pig feed; for poultry feed it is methionine, the content of which is only slightly higher in QPM than in regular maize. For the base model with long-term prices, average ingredient cost savings from using QPM in pig feed are as high as US$ 7.67/t for starter pigs and US$ 7.44/t for lactating sows in Brazil (Table 18). The corresponding cost savings in El Salvador are US$ 4.94/t for starter pigs and US$ 4.47/t for lactating sows. Maximum cost savings from using QPM in poultry feed are smaller but nonetheless substantial (Table 19): US$ 4.80/t for broilers and US$ 4.36/t for layers in Brazil, and US$ 4.39/t for broilers and US$ 3.69/t for layers in El Salvador.

Tables 20 and 21 show the optimal levels of the main ingredients in the different feeds. Quality protein maize substitutes completely for regular maize in virtually all the solutions to the model, indicating QPM's superiority as a feed ingredient. Moreover, the amount of soybean meal required is reduced by approximately 50% in diets with QPM, and the need for synthetic lysine is either eliminated (in poultry diets) or reduced

Table 18. Minimum cost of pig feed in Brazil and El Salvador, with and without QPM (base model)

Growth stage	Feed cost (US$/t) With QPM	Feed cost (US$/t) Without QPM	Cost savings (US$/t)	Cost savings (%)
Brazil				
Pigs				
1-15 kg	182.84	190.49	7.65	4.01
15-30 kg	157.49	165.16	7.67	4.65
30-60 kg	139.91	143.51	3.60	2.51
60-100 kg	133.43	137.95	4.52	3.28
Pregnant sows	129.63	132.18	2.55	1.93
Lactating sows	142.87	150.31	7.44	4.95
El Salvador				
Pigs				
1-15 kg	174.49	178.58	4.09	2.29
15-30 kg	155.40	160.34	4.94	3.08
30-60 kg	139.57	143.43	3.86	2.69
60-100 kg	133.02	137.69	4.67	3.39
Pregnant sows	128.75	131.99	3.25	2.46
Lactating sows	142.64	147.11	4.47	3.04

Note: Prices of main ingredients in the base model are (US$/t): regular maize, 120; QPM, 120; soybean meal, 240; sorghum, 114; and synthetic lysine, 3,000.
Source: LP model results.

substantially (in pig diets). These results are important, since they imply that imports of soybean meal and synthetic amino acids could be lowered considerably in importing countries such as El Salvador if QPM is used in feed instead of regular maize. In Brazil, the use of QPM would also substantially reduce the need for importing synthetic lysine and also reduce the amount of soybean meal in the diets, allowing Brazil to export more soybean meal.

Therefore, in Brazil the savings obtained from using QPM in poultry and pig feed are of the order of 4-5% for pig feed and 3-4% for poultry feed. The corresponding savings in El Salvador are in the range of 3-4% for both pig and poultry feed. Also, the potential of QPM to substitute for more expensive sources of protein is substantial. Quality protein maize would comprise approximately 80% of pig feed and 60% of poultry feed in both countries, reducing the need for soybean meal by about 50% and virtually eliminating the need for synthetic lysine.

Table 19. Minimum cost of poultry feed in Brazil and El Salvador, with and without QPM (base model)

	Feed cost (US$/t)		Cost savings	
Growth stage	With QPM	Without QPM	(US$/t)	(%)
Brazil				
Broiler chickens				
1-4 weeks	162.41	167.22	4.80	2.87
4-6 weeks	153.93	158.46	4.53	2.86
6-8 weeks	151.16	155.58	4.42	2.84
Layers				
1-6 weeks	153.53	157.89	4.36	2.76
6-12 weeks	140.05	143.95	3.89	2.70
12-20 weeks	129.83	133.34	3.51	2.63
20+ weeks	140.41	142.22	1.81	1.27
El Salvador				
Broiler chickens				
1-4 weeks	162.74	166.83	4.09	2.45
4-6 weeks	153.95	157.94	3.99	2.53
6-8 weeks	151.10	155.48	4.39	2.82
Layers				
1-6 weeks	153.59	157.27	3.69	2.34
6-12 weeks	139.71	143.35	3.65	2.54
12-20 weeks	128.95	132.43	3.48	2.63
20+ weeks	139.54	141.72	2.18	1.54

Note: Prices of main ingredients in the base model are (US$/t): regular maize, 120; QPM, 120; soybean meal, 240; sorghum, 114; and synthetic lysine, 3,000.
Source: LP model results.

Table 20. Average optimal level (kg/t) of main ingredients in pig feed in Brazil and El Salvador, with and without QPM

	Regular maize	QPM	Soybean meal	Synthetic lysine
Brazil				
Pigs, all growth stages				
With QPM	0	813	72	1.1
Without QPM	808	..	121	1.9
Pregnant and lactating sows				
With QPM	61	797	41	0.2
Without QPM	853	..	90	0.9
El Salvador				
Pigs, all growth stages				
With QPM	0	778	120	0.0
Without QPM	785	..	165	0.8
Pregnant and lactating sows				
With QPM	0	835	49	0.0
Without QPM	840	..	118	0.1

Source: LP model results.

Table 21. Average optimal level (kg/t) of main ingredients in poultry feed in Brazil and El Salvador, with and without QPM

	Regular maize	QPM	Soybean meal	Synthetic lysine
Brazil				
Broilers				
With QPM	0	650	202	0.0
Without QPM	657	..	261	0.4
Layers				
With QPM	0	635	97	0.0
Without QPM	664	..	154	0.2
El Salvador				
Broilers				
With QPM	0	604	235	0.0
Without QPM	635	..	276	0.2
Layers				
With QPM	0	593	118	0.0
Without QPM	626	..	173	0.1

Source: LP model results.

Sensitivity Analysis

As discussed above, the price structure of the main ingredients used in the LP model corresponds to price ratios that may or may not reflect actual relative prices faced by feed producers in the two countries. In Brazil, relative prices of ingredients favor the use of more soybean meal and less synthetic lysine in the feed. The case is the opposite in El Salvador, where the price of synthetic lysine is lower and all soybean meal is imported and thus more expensive than in Brazil. The synthetic lysine price used in the base model is the average price over the last five years and is also an international price. In El Salvador greater availability and lower prices of sorghum have traditionally favored its use in commercial feed, especially when shortages of white maize occur. The strength of the results of the base model was tested by changing the price ratios of the main ingredients to gauge the sensitivity of the cost savings from using QPM to changes in the prices of the main ingredients.

Increases in the prices of soybean meal, sorghum, and synthetic lysine will clearly enhance the benefits of QPM. Thus the sensitivity analysis concentrates mostly on price changes that would reduce the savings from using QPM: reductions in the prices of ingredients for which QPM potentially can substitute or increases in the price of QPM relative to regular maize. To perform sensitivity analysis over a relevant range of prices, the opportunity costs of ingredients, obtained from results of the base model, were used (Tables 22 and 23). The price ranges shown in Table 22 indicate that, for pig feed in Brazil, the price of QPM could be as much as 9% higher than the price of regular maize (US$ 131/120) without changing the optimal feed composition. In contrast, the maximum QPM price increase in El Salvador can only be about 4% over the price of

Table 22. Price ranges (US$/t) of main pig feed ingredients over which base model results with QPM remain unchanged, Brazil and El Salvador

Growth stage	Regular maize	QPM	Soybean meal	Sorghum	Synthetic lysine
Brazil (minimum-maximum)					
Pigs					
1-15 kg	108-INF	79-131	207-278	..	0 - 3,371
15-30 kg	113-INF	0-127	223-280	..	1,178 - 4,307
30-60 kg	117-INF	118-122	239-243	..	1,178 - INF
60-100 kg	117-INF	118-122	239-243	..	1,178 - INF
Pregnant sows	117-INF	119-123	210-249	..	429 - INF
Lactating sows	113-INF	0-127	223-280	..	1,178 - 4,307
El Salvador (minimum-maximum)					
Pigs					
1-15 kg	114-INF	80-125	232-258	101-INF	2,292 - INF
15-30 kg	114-INF	80-125	232-258	101-INF	2,292 - INF
30-60 kg	117-INF	104-124	237-287	107-INF	1,422 - INF
60-100 kg	117-INF	104-124	237-287	107-INF	1,422 - INF
Pregnant sows	120-INF	102-121	234-295	112-INF	678 - INF
Lactating sows	114-INF	80-125	232-258	101-INF	2,292 - INF

Note: Ingredient prices used in the base model are (U$/t): regular maize, 120; QPM, 120; soybean meal, 240; sorghum, 114; and synthetic lysine, 3,000. INF = infinity.
Source: LP model results.

regular maize (125/120) before the optimal pig feed composition changes. The maximum price premium that QPM could command in poultry feed is 6% in both Brazil and El Salvador (Table 23).

The base model results are more sensitive to changes in the price of soybean meal. The ratio of soybean meal to regular maize price in the base model is set at 2 (that is, a soybean meal price of US$ 240/t). In some cases, a reduction of only US$ 1/t in the price of soybean meal changes the optimal feed composition, particularly for pig feed. Since this price ratio varies substantially, especially in Brazil, the model was run with both a lower price ratio (1.5) and a higher price ratio (2.5) for pig and poultry feed and for both countries.

Synthetic lysine is another ingredient that potentially competes with QPM in feed. In both Brazil and El Salvador, this amino acid is imported and, although the international price has declined substantially in the last two years, it is still about US$ 3/kg. Tables 22 and 23 indicate that, with only one exception (feed for starting broilers in Brazil), the price of lysine would have to drop below US$ 2.30/kg to change the optimal feed rations. Thus the results of the base model are strong in this respect. Nevertheless, the model was run for a synthetic lysine price of US$ 2/kg to estimate the effect on the optimal level of QPM in the diets and the potential cost savings.

Table 23. Price ranges (US$/t) of main poultry feed ingredients over which base model results with QPM remain unchanged, Brazil and El Salvador

Growth stage	Regular maize	QPM	Soybean meal	Sorghum	Synthetic lysine
Brazil (minimum-maximum)					
Broiler chickens					
1-4 weeks	113-INF	80-127	224-245	..	2,640-INF
4-6 weeks	115-INF	77-126	224-258	..	1,878-INF
6-12 weeks	115-INF	77-126	224-258	..	1,783-INF
Layers					
1-6 weeks	115-INF	73-126	224-258	..	1,783-INF
6-12 weeks	117-INF	79-124	214-265	..	1,577-INF
12-20 weeks	118-INF	84-122	219-265	..	1,195-INF
20+ weeks	118-INF	84-122	219-265	..	1,195-INF
El Salvador (minimum-maximum)					
Broiler chickens					
1-4 weeks	114-INF	118-127	176-246	104-INF	2,126-INF
4-6 weeks	114-INF	118-126	187-246	104-INF	2,093-INF
6-12 weeks	114-INF	118-127	176-296	104-INF	2,126-INF
Layers					
1-6 weeks	114-INF	118-126	187-246	104-INF	2,093-INF
6-12 weeks	115-INF	109-125	238-281	105-INF	1,897-INF
12-20 weeks	118-INF	98-122	219-281	110-INF	1,195-INF
20+ weeks	118-INF	98-122	219-281	110-INF	1,195-INF

Note: Ingredient prices used in the base model are (US$/t): regular maize, 120; QPM, 120; soybean meal, 240; sorghum, 114; and synthetic lysine, 3,000. INF = infinity.

Source: LP model results.

The LP model for El Salvador was run with reductions in the sorghum price from the base price of US$ 114/t to US$ 102/t and then to US$ 96/t, since only slight reductions in sorghum price would change the feed composition (see Tables 22 and 23).

To account for possible differences between international and domestic prices in Brazil and El Salvador, the model was also run using a lower price for maize but maintaining the price ratios. This was the only case in which more than one price was changed, since the prices of QPM, soybean meal, and sorghum also changed to maintain the original price ratios.

Finally, the LP models were also run under two additional assumptions about QPM. The first was that QPM has a 10% higher total energy and protein content than regular maize (the prices of the base model were retained). The second assumption was that only the total protein content of QPM is 10% higher than that of regular maize (the energy content for both maize types remains the same). These cases provided an estimate of the further potential for QPM as an animal feed if indeed QPM proves to have a higher total protein and energy content than regular maize, as claimed in some studies (see Rostango et al. 1988, Peixoto et al. 1990, Weigel 1991, Feedstuffs 1991). Table 24 shows the model runs performed to do the sensitivity analysis and the changes made in each case.

Table 24. Changes made for sensitivity analysis of model

Ingredient	Original price (base model)	New price (sensitivity analysis)
	(US$/t)	
Regular maize	120	108[a]
QPM	120	126
QPM	120	132
Soybean meal	240	180
Soybean meal	240	300
Sorghum (El Salvador)	114	102
Sorghum (El Salvador)	114	96
Synthetic lysine	3,000	2,000
QPM protein and energy content relative to regular maize:		
	(Ratios)	
a) Protein	1.0	1.1
Energy	1.0	1.1
b) Protein	1.0	1.1
Energy	1.0	1.0

a The prices of QPM, soybean meal, and sorghum are also set at 108, 216, and 102.60 US$/t, respectively.

Both cost savings and optimal content of QPM in the different feed types drop substantially when a 5% price premium is assumed for QPM over regular maize (Figures 1-4). Moreover, when a 10% price premium is assigned to QPM (a price of US$ 132/t), it ceases to be economically attractive for feed producers. Therefore any

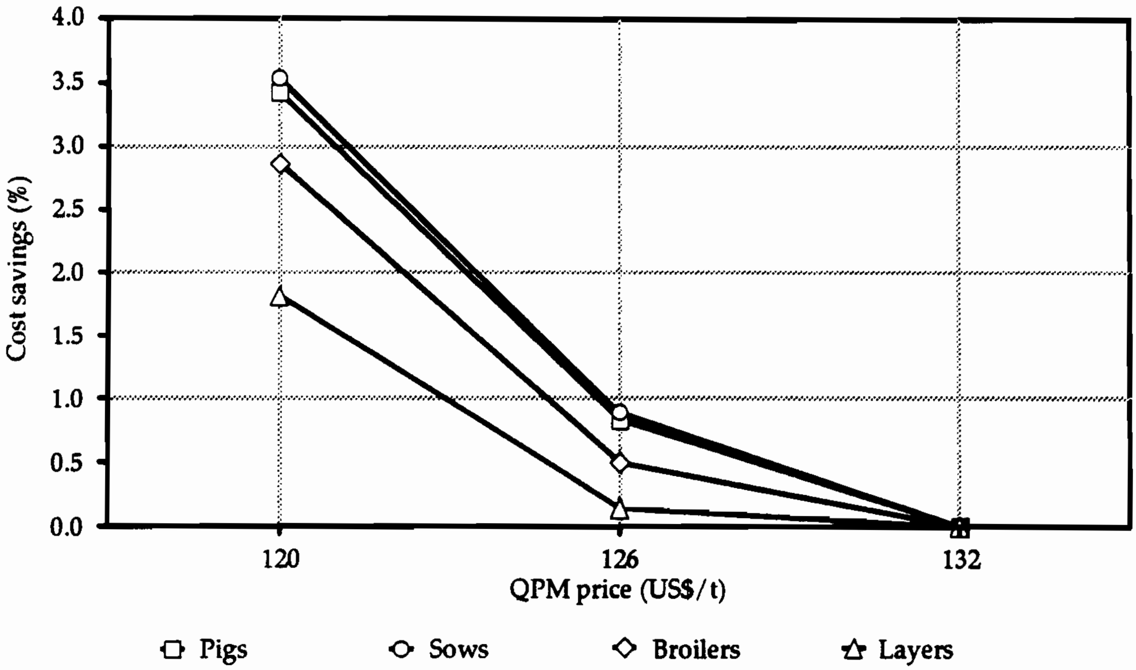

Figure 1. Feed cost savings from using QPM, at different QPM prices, Brazil.

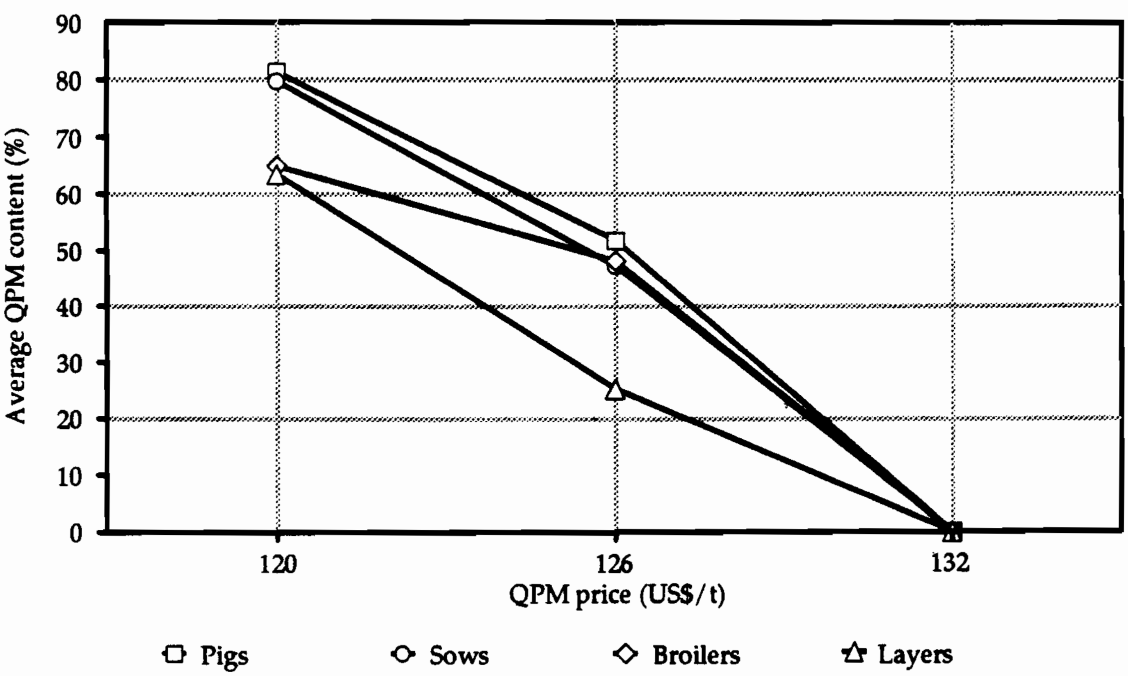

Figure 2. Content of QPM in pig and poultry feed, at different QPM prices, Brazil.

price premium offered by the feed industry to potential QPM producers in Brazil and El Salvador could not exceed 5%. If QPM is to have potential as a feed ingredient in these countries, it must compete with regular maize at the same price, since feed producers will not be willing to pay substantial price premiums for QPM.

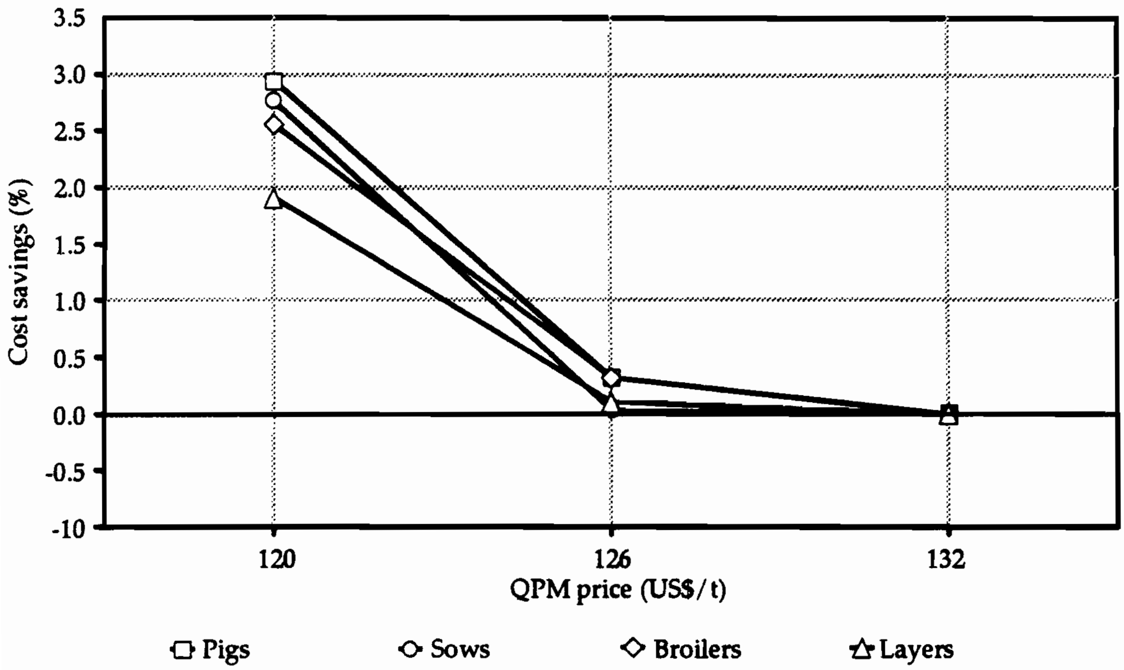

Figure 3. Feed cost savings from using QPM, at different QPM prices, El Salvador.

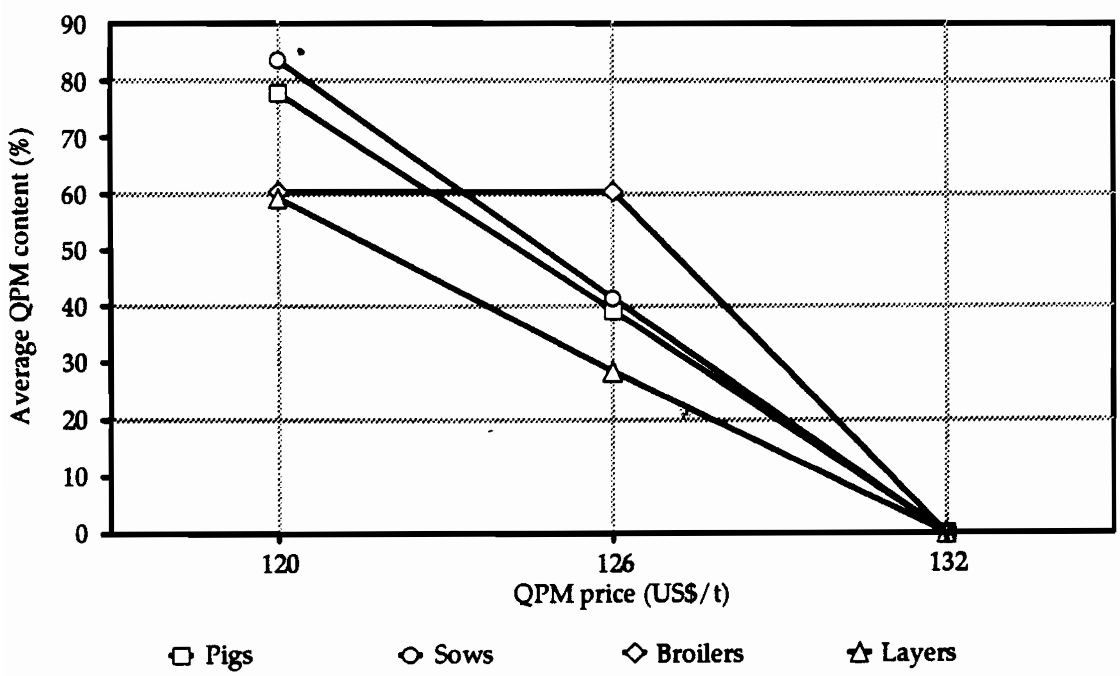

Figure 4. Content of QPM in pig and poultry feed at different QPM prices, El Salvador.

As expected, percentage feed cost savings from using QPM are negatively related to price changes in soybean meal (Figures 5-8). It is interesting to note that even at a very low price for soybean meal (a soybean meal-to-regular maize price ratio of 1.5, a case common in Brazil), cost savings per ton are still above 1.5% for pigs, and the proportion

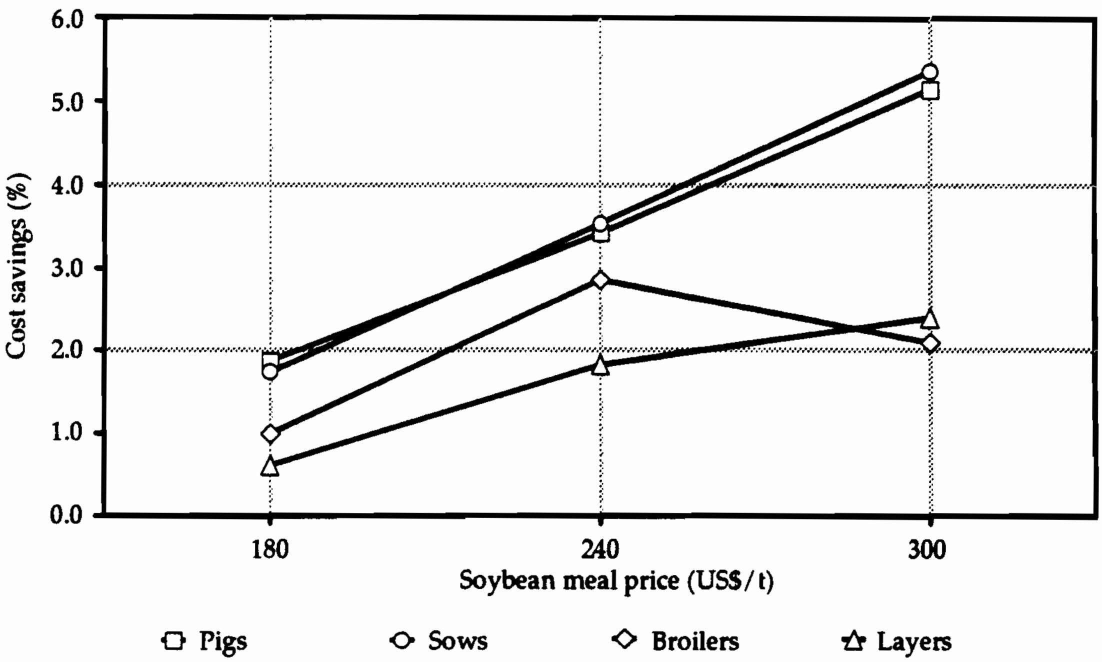

Figure 5. Feed cost savings from using QPM, given different soybean meal prices, Brazil.

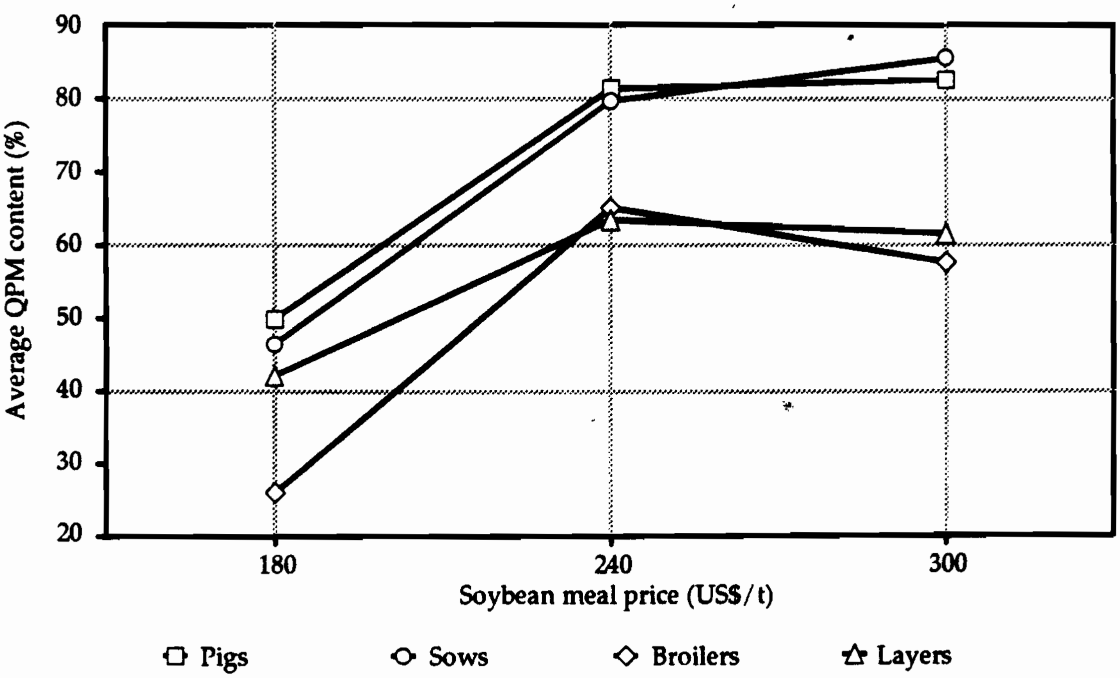

Figure 6. Content of QPM in pig and poultry feed, given different soybean meal prices, Brazil.

of QPM in the diet is about 50% (Figures 5-6). At very high soybean meal prices (a soybean meal-to-regular maize price ratio of 2.5), cost savings are substantially higher, especially for pig feed in Brazil, although the level of QPM in the different feed types does not increase dramatically from the base case.

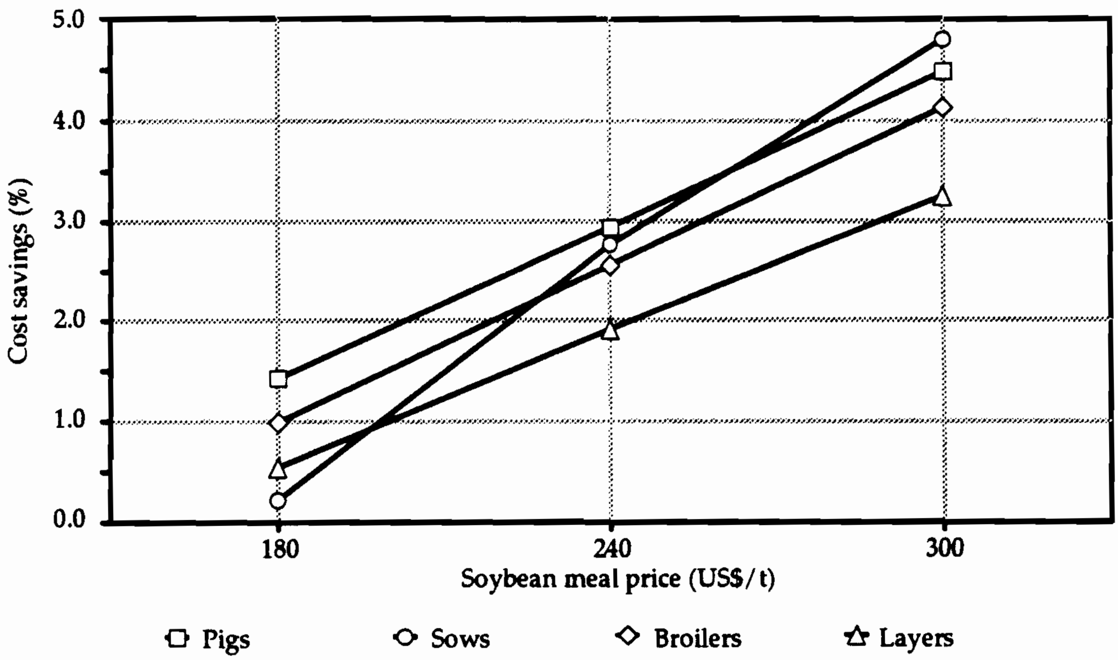

Figure 7. Feed cost savings from using QPM, given different soybean meal prices, El Salvador.

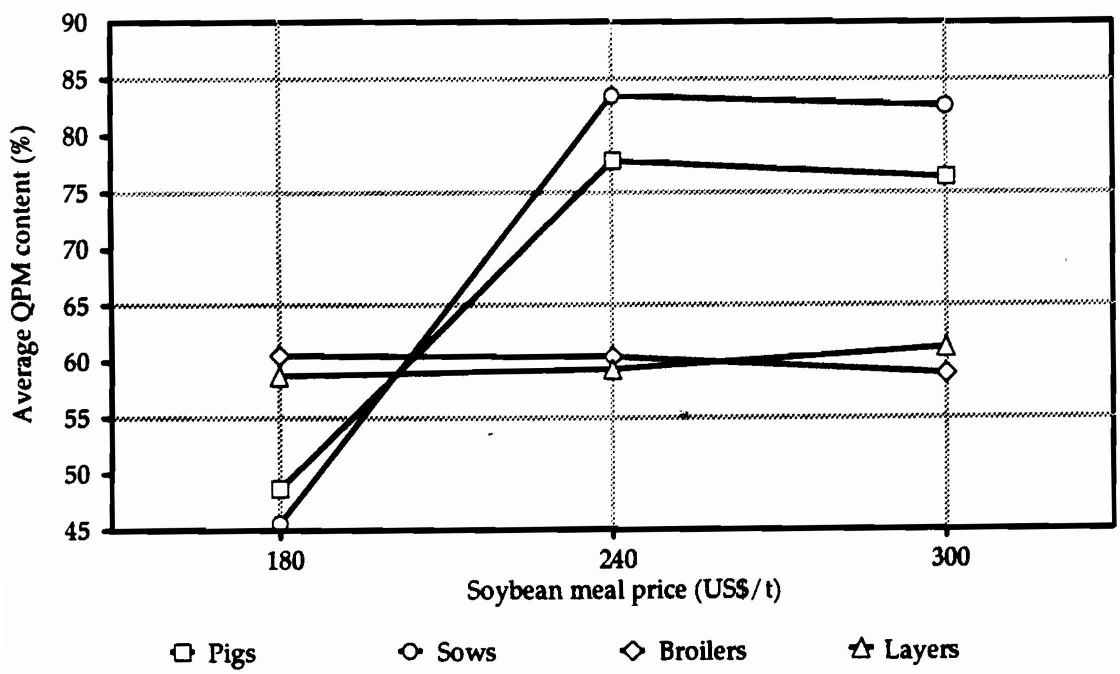

Figure 8. Content of QPM in pig and poultry feed, given different soybean meal prices, El Salvador.

In El Salvador, a sorghum-to-regular maize price ratio of 0.80 (i.e., a sorghum price of US$ 96/t) would virtually eliminate all the savings from using QPM in pig feed (Figures 9 and 10). Historically, the price ratio of sorghum to regular maize in El Salvador has been approximately 0.9. Model runs with this ratio produce the same cost

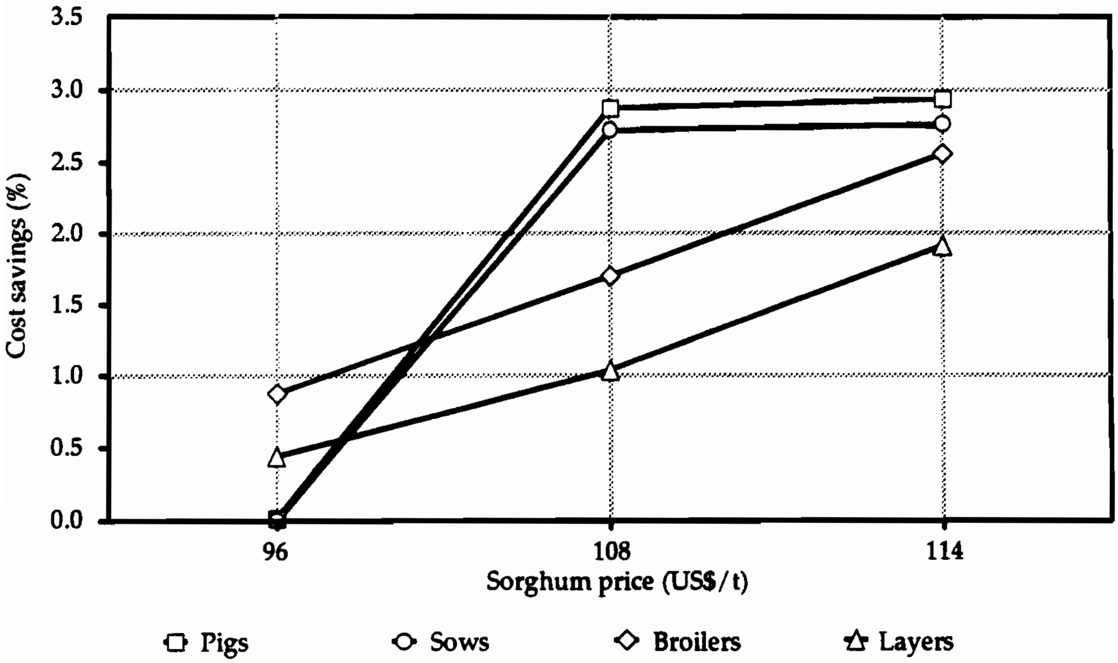

Figure 9. Feed cost savings from using QPM, given different sorghum prices, El Salvador.

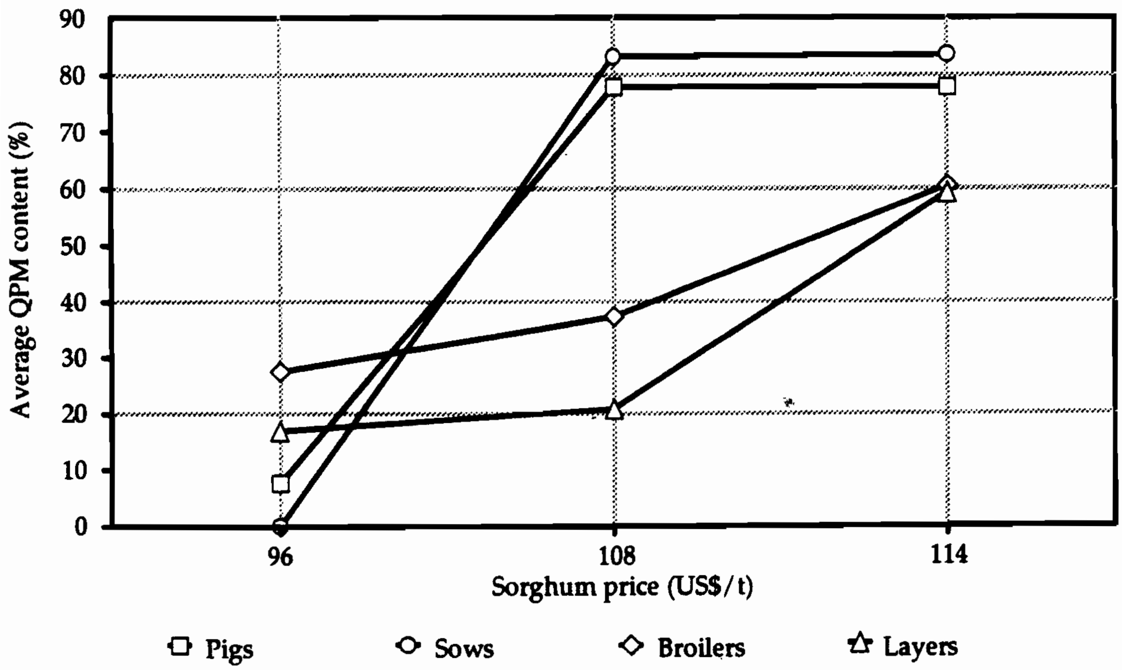

Figure 10. Content of QPM in pig and poultry feed, given different sorghum prices, El Salvador.

savings for pig feed as the base model with a ratio of 0.95. Cost savings in poultry feed are more sensitive to slight declines in sorghum prices from the base case, although QPM still comprises about 25% of poultry feed even at the lowest sorghum price assumed.

The cost savings obtained in the base model are not sensitive to a further drop in synthetic lysine prices, in this case from US$ 3/kg to US$ 2/kg (Table 25). Moreover, the optimal QPM content in the feed types is still very high, averaging 800 kg/t for pig feed and 600 kg/t for poultry feed in both Brazil and El Salvador. Table 25 also shows the effect of a lower price of maize and keeping the price ratios as in the base model. Although percentage cost savings are somewhat lower, they still average US$ 5/t for pig feed and US$ 3/t for poultry feed in both countries. The largest drop in savings is for layer hens, in which case the content of QPM in the ration also drops to about 400 kg/t.

Table 25. Cost savings and average QPM content in pig and poultry feed, given lower regular maize and synthetic lysine prices, Brazil and El Salvador

Sensitivity case	Cost savings (%)	QPM content (kg/t)
1) Lower synthetic lysine price		
Brazil		
Pigs	2.99	813
Sows	3.04	797
Broilers	2.28	650
Layers	1.59	635
El Salvador		
Pigs	2.42	798
Sows	2.63	838
Broilers	2.27	578
Layers	1.67	592
2) Lower regular maize price[a]		
Brazil		
Pigs	2.99	811
Sows	3.00	797
Broilers	2.08	644
Layers	0.92	326
El Salvador		
Pigs	2.45	774
Sows	1.73	824
Broilers	1.87	604
Layers	0.94	411

Source: LP model results.

a Regular maize price set at US$ 108/t and the prices of QPM, soybean meal, and sorghum at 108, 216, and 102.60, respectively.

Table 26 shows the effect of including QPM in animal feed if QPM is assumed to have either 1) a superior total energy *and* protein content or 2) only a superior protein content. Under the first scenario (10% higher energy and protein in QPM), cost savings would be much greater than in the base case. Average pig feed cost savings would be 11% in Brazil and close to 10% in El Salvador. In the specific case of starting pig feed in Brazil, the total cost of feed with QPM would be US$ 158.66/t compared to US$ 190.49/t without QPM. This represents a US$ 31.83/t (16.7%) feed cost savings. This is the only case in which QPM could command a 10% price premium over regular maize and still constitute at least 50% of the feed ration for some growth stages. For example, the average QPM-to-regular maize price ratio could be as high as 1.13 in Brazil and 1.14 in El Salvador, and pig feed producers would still use QPM in the same proportion as shown in Table 26.

Under the second scenario (10% higher protein content only in QPM), cost savings are only slightly higher than for the base case, indicating that the cost savings under the

Table 26. Cost savings, maximum QPM-to-regular maize price ratio, and optimal QPM content in pig and poultry feed, assuming a higher energy and protein content in QPM versus regular maize, Brazil and El Salvador

Country and feed type	Cost savings (US$/t)	Cost savings (%)	QPM content in feed (kg/t)	Maximum QPM-to-regular maize price ratio[a]
	Case A: QPM energy and protein 10% higher than regular maize			
Brazil				
Pigs	16.44	10.85	707	1.13
Sows	12.78	9.05	736	1.07
Broilers	8.66	5.34	561	1.11
Layers	6.24	4.37	546	1.07
El Salvador				
Pigs	14.31	9.41	668	1.14
Sows	11.63	8.33	675	1.09
Broilers	8.40	5.20	542	1.07
Layers	6.25	4.39	512	1.08
	Case B: QPM protein 10% higher than regular maize			
Brazil				
Pigs	6.91	4.56	838	1.04
Sows	5.68	4.02	658	1.06
Broilers	4.92	3.04	654	1.05
Layers	2.65	1.85	635	1.02
El Salvador				
Pigs	6.12	4.11	804	1.05
Sows	4.61	3.30	840	1.03
Broilers	4.72	2.92	616	1.05
Layers	2.88	2.02	596	1.02

Source: LP model results.
a Maximum QPM-to-regular maize price ratio at which the feed composition remains unchanged.

first scenario are mostly a result of the assumed higher energy level. Therefore, the development of high energy (high oil) QPM materials appears to be a promising research strategy. It should be noted, however, that the figures in Table 26 are results for a potential situation in which QPM would not only have greater lysine and tryptophan content but also greater overall protein and energy, making it a superior source of both energy and protein.

In conclusion, results of the sensitivity analysis suggest that, except for the effect occurring when the QPM price is increased, cost savings from using QPM in pig feed are strong and stand the test of price changes in some ingredients that would potentially compete with QPM. The advantage of QPM is enhanced if the soybean meal-to-regular maize price ratio is 2.5, and the price of QPM is the same as regular maize. In contrast a very low sorghum-to-regular maize price ratio (e.g., 0.80) would reduce the advantage of QPM. Further reductions in the price of synthetic lysine will not affect cost savings from using QPM in feed rations. However, feed producers are not likely to offer any price premiums over the price of regular maize to QPM producers. At most this premium would be about 3%, unless QPM is proven to have other advantages over regular maize (especially higher total energy), in which case the price premium could be as high as 10%.

Savings Projections for the Feed Industry

Using the results of the base LP model and the sensitivity analysis, potential overall savings for the feed industry from using QPM were estimated for El Salvador and Brazil. The following assumptions were made in obtaining these estimates. Animal feed production in the two countries over the next several years will be as projected in Table 4 for El Salvador and Table 14 for Brazil. It is also assumed that within the next two years each country will release a QPM hybrid capable of yielding 3 t/ha on average. Commercial production of QPM is assumed to begin in 1994 in both countries on 1% of the 1990 national maize area (see Tables 2 and 10), and will increase at a rate of 10% per year until the year 2000. All QPM production is used by the feed industry in the pig or poultry feed growth stage in which the savings are greatest (Tables 18 and 19) and in the proportions indicated by the base model results (Tables 20 and 21). A 10% interest rate is applied to discount the savings to 1991, and a 10-year planning horizon is assumed, 1991-2000. The same estimates were made for a case in which feed producers pay a 5% price premium for QPM over regular maize. The cost savings indicated by this sensitivity case were used in the industry savings estimates to estimate the net cost savings for the feed industry if QPM received a price premium.

With no price premium over regular maize, the Net Present Value (NPV) of savings from using QPM in pig feed would be US$ 16 million over the 10-year period, or a 10-year annuity of US$ 2.6 million per year in Brazil (Table 27). If QPM is used in poultry feed, the NPV of savings drops to US$ 13 million for the period, or an annuity of US$ 2.1 million per year. The savings are much more modest in El Salvador and approximately the same for pig and poultry feed, with an NPV of US$ 265,000 or annuity of US$ 43,000 per year.

With the exception of pig feed production in Brazil, offering a 5% price premium for QPM would reduce estimated total cost savings to less than 25% of the savings without the premium. This results from the sensitivity of cost savings to an increase in the QPM price. For Brazilian pig feed producers, the advantage of using QPM as a cost-saving ingredient would be only modestly attractive at a price premium of 5%. These results suggest that QPM technology can be adopted over a substantial maize area only if farmers are willing to receive the same price for QPM as for regular maize, since even moderate price premiums that the feed industry may be willing to pay would eliminate virtually all incentives to use QPM in commercial feed.

The large differences in overall cost savings in the two countries reflect the difference in their maize areas and the magnitude of the cost savings from using QPM as a commercial feed ingredient. The savings in Brazil without price incentives appear to strengthen the possibility of maintaining a small QPM breeding program within the Brazilian maize research system to develop new varieties and solve some of the remaining problems in QPM, especially poor husk cover. Private industry should be willing to share a small portion of these savings with potential QPM producers in the form of price premiums and with researchers working on QPM. As seen in Table 27, however, this price premium would be very small.

Although total feed cost savings for El Salvador are very low even without a QPM price premium, the assumed area under QPM in the early years of adoption is also very small, only 5,000 ha by the year 2000 (less than 2% of 1990 national maize area). Should adoption occur faster, total feed cost savings would increase substantially (as they would in Brazil if a faster rate of adoption is assumed). Given the modest size of the Salvadoran feed industry, which produced a total of 300,000 t of commercial feed in 1990 (Table 4), the savings may be significant.

Table 27. Projected cost savings from using QPM in pig and poultry feed in Brazil and El Salvador, with and without a 5% price premium paid for QPM, 1991-2000

	Brazil		El Salvador	
	Pigs	Poultry	Pigs	Poultry
No price premium for QPM				
NPV of savings (US$ 000)	16,089	12,992	265	264
10-year equivalent annuity (US$ 000/yr)	2,618	2,114	43	43
5% price premium for QPM				
NPV of savings (US$ 000)	8,367	2,896	63	61
10-year equivalent annuity (US$ 000/yr)	1,362	471	10	10

Note: A 10% interest rate and a planning period of 1991-2000 were assumed for the savings estimates. See text for other assumptions.

Source: LP model results.

Several general conclusions can be drawn from these results. Quality protein maize has greater potential as a cost-saving ingredient in pig feed than in poultry feed. This difference results from QPM's greater lysine content and the distinct nutritional requirements of chickens and pigs (lysine is more important in pig nutrition). The larger and more sophisticated the feed industry is, the greater the savings for pig feed can be. The average savings for the feed industry when QPM is used for pig feed in Brazil, US$ 2.6 million per year, are such that the costs of developing QPM cultivars should be more than offset for the period considered. This makes QPM an attractive investment for the Brazilian national maize research program.

For the case of El Salvador, the potential savings are only US$ 43,000 per year if QPM is used in either poultry or pig feed. Given that in El Salvador commercial poultry production is much more developed than pig production (the poultry industry accounts for 80% of commercial feed production), QPM may have greater potential for poultry feed. The methionine content in QPM appears to be higher than in regular maize (e.g., Peixoto et al. 1990). In fact, in the LP models in this study the methionine content of QPM is assumed to be slightly higher than that of regular maize (see Table 1), which may help to explain the advantage of QPM in poultry feed. Synthetic methionine, which is more expensive than synthetic lysine, is usually required in poultry feed as its content in the main feed ingredients, especially soybean meal and maize, is low.

However, total savings achieved by the feed industry from introducing QPM in El Salvador seem much lower than the costs likely to be incurred in shifting to a new crop, which are not considered in this study. Therefore, adoption of QPM would have to proceed spontaneously, without incentives from either industry or government. Thus QPM may have more potential among small-scale farmers who could use it for direct consumption at home and to feed their animals, and the government's role would be limited to making QPM seed available. Another possibility is that QPM could be grown as a specialty crop by large-scale farmers contracted by the poultry industry. This possibility is discussed in more detail below.

The other main difference between QPM and regular maize, the leucine-to-isoleucine ratio, was not explored in this study. The lower level of this ratio in QPM is claimed to give it an important advantage over regular maize. However, due to the nature of cost minimization, the lower leucine-to-isoleucine ratio in QPM was penalized in the LP models as ingredients with higher nutrient levels are preferred. If improved nutritional qualities such as this had been accounted for in the models, perhaps the potential of QPM as a feedstuff would have been enhanced.

Potential QPM supply and demand

In countries such as Brazil, where the pig industry is large and well developed, the marketing of QPM from producers to the feed industry is expected to pose few problems. The feed and pig industries in Brazil are interested in QPM, especially as a partial substitute for soybean meal and synthetic lysine. Vertically integrated pig operations contract farmers as pig growers. These growers, in turn, produce their own maize and combine it with company-supplied concentrate to form the pig ration. They could grow QPM instead of regular maize and use it domestically along with the feed concentrate, which could be modified to account for the nutritional characteristics of QPM (according to the model results, the modified concentrate would probably contain much less soybean meal and no synthetic lysine).

The potential of QPM to move through marketing channels in El Salvador appears more limited. A system in which pork producers contract maize farmers to raise pigs does not exist in the country. However, large-scale farmers are commonly contracted to produce maize and sorghum for the feed industry in El Salvador. Should these farmers become interested in producing QPM for the feed industry, this alternative also offers a promising solution to the QPM identification problem.

Subsistence farmers in both countries potentially could benefit as both producers and consumers of QPM for direct human consumption and for on-farm animal feed. For such farmers the potential benefits of using QPM may be enhanced by the fact that QPM has been shown to have a much greater advantage over regular maize when it is the sole source of feed for pigs and chickens (e.g., Maner 1975, 1983).

The development and promotion of a QPM hybrid seems to be a natural next step in introducing and diffusing this technology in countries where QPM materials have been developed. If the feed industry is interested in such a product, they will demand it from maize producers who, in turn, will request it from maize seed companies. The role of the national maize program would consist of making basic seed available to commercial seed companies and to improve on the characteristics of the material, especially remaining problems such as insufficient husk cover. Biological studies in regions where pig production is strongest could also be an effective way to help disseminate the available materials.

Relative prices of QPM and regular maize

The LP model results above indicate that the ingredient costs of pig feed can be reduced by using QPM. These savings are modest but attractive, depending on the QPM-to-regular maize and soybean meal-to-regular maize price ratios. If feed producers are profit maximizers, they will prefer and demand QPM, and they should be willing to pay a small premium for QPM over regular maize, should that be necessary. The amount of the premium would be determined by market forces and would be a portion of the cost savings from using QPM. The minimum premium that maize producers would be willing to accept is that which compensates them for the extra risk (real or perceived) of producing QPM and the production cost differential, if there is any.

When interviewed, feed producers in both countries indicated an interest in QPM. Integrated feed producers in Brazil find QPM attractive as a substitute for synthetic lysine and soybean meal, especially in pig feed. In El Salvador, poultry producers, mostly integrated into feed production for their own use, are concerned with the reliability of their grain sources, especially imported yellow maize (see Tables 1 and 2 for an indication of variability in grain production in El Salvador). Salvadoran poultry producers have expressed an interest in a yellow QPM cultivar that could be promoted among large commercial farmers. These farmers could produce QPM under contract with the poultry industry, thus ensuring domestic supplies of yellow maize and reducing imports of yellow maize, soybean meal, and synthetic lysine. Poultry producers also seemed willing to pay a small premium for QPM. Total cost savings to the feed industry in El Salvador, however, have been shown to be sensitive to the price of QPM relative to regular maize and the price of sorghum. Either modest price premiums for QPM or low sorghum prices would wipe out any cost advantage from using QPM and hence reduce interest in QPM as a feed ingredient.

The identification problem

The greatest potential problem for QPM as a commercial feed ingredient is that physically QPM and regular maize are identical. Most commercial feed producers do not have the technology to perform amino acid tests of feed ingredients. If the commercial feed industry is to use QPM in significant quantities, practical methods for determining the lysine and tryptophan content of maize would be necessary.

A different color from that of regular maize could provide an identifier for QPM in some countries. Grain color is not as important for pig production as for poultry production. Moreover, grain color is a characteristic that can be incorporated easily in maize varieties. As mentioned earlier, in Brazil, where most maize is yellow, the first QPM variety released is white, although it has been promoted for direct human consumption rather than for the feed industry. The opposite is true in El Salvador, where most of the maize is white: a yellow QPM hybrid would be identified readily. Once it can be identified, QPM can be treated as a different grade of maize and stored separately from regular maize in feed mill silos.

Contracting maize farmers to produce QPM for the feed industry (El Salvador), or QPM production by pig growers (Brazil), are two alternatives for dealing with the identification problem. If farmers produce only QPM and use it to feed pigs, no grain would leave the farm and care would be necessary only to ensure the availability of quality QPM seed every year.

The future price of artificial lysine

One factor determining the potential of QPM in pig feed is the price of synthetic lysine, especially in Brazil. International prices of synthetic lysine dropped sharply in 1991. However, prices are currently about US$ 3/kg (Table 17), and thus any ingredient with a high lysine content will still compete favorably in the formulation of pig feed. The synthetic lysine price seems to be moving towards further, although more moderate, reductions over the next five years. For example, synthetic lysine prices in Mexico, the only producer of synthetic amino acids in Latin America, are much lower than in Brazil. In addition, a new synthetic lysine plant was opened recently in the United States by the Archer Daniel Midland Company (ADM). This plant is expected to increase world synthetic lysine production substantially (Feedstuffs 1990). The prospects for lower synthetic lysine prices suggest that the potential for QPM may not be as good as it appears presently in countries such as Brazil, where synthetic lysine prices are relatively high. The LP model results indicate, however, that the price of synthetic lysine would have to decrease to about US$ 2/kg to have any substantial effect on the optimal level of QPM in the feed, a price decline that is not very likely to occur in the long run (Jerry Weigel, ADM, 1991, pers. comm.).

The potential for QPM in feed in Mexico: a brief example

Mexico imports substantial quantities of maize, mainly for feed. A relatively small percentage of domestic maize (almost all of it white) is used for feed because of high official prices. Soybean meal and sorghum are popular protein and energy sources in feed. Mexican regulations as well as customs discourage the use of domestically produced maize for animal feed. As indicated previously, synthetic lysine is produced domestically and is relatively inexpensive. Pork and poultry production are highly developed in some regions of the country, especially the northwest. The use of QPM in pig feed would not seem to have much potential to lower feed production costs in Mexico, given domestic maize price distortions, the low price of artificial lysine, and current policies in the maize sector. However, Mexico's agricultural sector (and its economy in general) are undergoing major restructuring as a result of negotiations over the North American Free Trade Agreement with the United States and Canada. Therefore, the situation may change in the short run and QPM may become attractive as an alternative feed ingredient.

The LP models used in this study were run for the state of Sonora using current ingredient prices in Mexico and the international prices for yellow maize and QPM (VIMIFOS 1991). The results indicate that a yellow QPM hybrid could have substantial promise as an ingredient in feed rations for starter pigs if it commanded a price premium of 10% or less over the price of imported regular yellow maize. Quality protein maize would comprise 47% of pig feed in this case, reducing the need for soybean meal by 6% and synthetic lysine by 28%. These results are consistent with base model results obtained in this study and indicate that, should the price of maize in Mexico approach the international price, QPM would have potential as a cost saving feed ingredient in Mexico.

Factors Affecting the Potential Supply of Quality Protein Maize

The results presented above indicate that, in countries where the feed industry is highly developed, QPM could compete favorably as an ingredient in pig feed and provide attractive cost savings, especially if sorghum and soybean meal prices are high relative to the maize price and no premium is paid for QPM. The following discussion highlights the main issues that must be addressed in introducing and promoting QPM varieties and hybrids. The discussion includes an update on some of the issues discussed in a study of QPM in the early 1980s (Pinstrup-Andersen 1982).

Production costs of QPM relative to regular maize
Since average yields of new QPM materials are now identical to those of regular maize hybrids, it is not expected that QPM production costs will differ from the costs of producing regular maize (seed costs may be an exception). Quality protein maize varieties and hybrids do not have special production or handling requirements, so production costs per ton should be similar, reflecting only small differences in seed price.

If farmers using traditional seed and methods adopt a QPM variety or hybrid, the yield increase required for adoption of the variety to be profitable may not be very high. Thus these farmers may lower their per-unit production costs by growing QPM. Even though this is also true for any other improved maize material, and the advantage of QPM may be realized only if there is a market for it, the added nutritional benefits of QPM should make it more attractive than alternative varieties or hybrids of regular maize. However, QPM may still possess some disadvantages as an alternative crop for maize farmers. These disadvantages, which could result in higher marketing and storage costs, are discussed below.

Comparison of QPM and regular maize
Several characteristics of QPM and regular maize are assumed to be identical for the purposes of this study, including yield, husk cover, and storability. However, storage problems are still present. According to Brazilian farmers in the state of Minas Gerais, white QPM (BR-451) left in the field (a form of storage) suffered substantial damage in 1991, mainly because the cultivar's poor husk cover invites rates of weevil infestation higher than those occurring in other maize varieties (García and López-Pereira, 1992).

Due to these and other problems, QPM technology would appear riskier than regular maize. Quality protein maize yields are expected to be no higher than those of regular maize and perhaps more variable. Effective yields may be reduced if the grain is stored for long periods. Markets for QPM are not developed and thus marketing risks for QPM will be greater, at least initially. Farmers who know older varieties of Opaque-2 maize may recall past problems and may be reluctant to produce QPM. Also, in general, the *perceived* risk of a new technology (QPM) by potential adopters is usually greater than for an established technology (regular maize), simply because farmers are not familiar with it. Therefore, farmers expect to be compensated for the extra risk they bear if they try new QPM varieties. The compensation usually takes the form of extra yield or, for the case of QPM, greater expected returns from the technology, probably through a price premium.

Seed production and distribution (hybrids vs. OPVs)
Private seed companies would only be interested in developing hybrid QPM, especially in large countries where the seed industry is well developed. The development of hybrids would reduce the potential contamination problem; the Opaque-2 gene is recessive and can be lost easily when second- or third-generation seed of open-pollinated varieties (OPVs) is used.

The prospects for QPM seed production are better where a private maize seed industry is established. In Brazil, the seed production and regulation agency, Servico de Producao de Sementes Basicas (EMBRAPA/SPSB), is in charge of producing basic maize seed for sale. This agency is connected to a network of about 25 small private seed companies and several larger seed companies that produce and market commercial maize seed (both hybrids and OPVs). These companies, and one private seed company, already sell BR-451 seed regionally. The Salvadoran seed industry is also well developed, possessing an effective system of production, certification, and quality control (García et al. 1990). Salvadoran farmers use the highest percentage of certified maize seed in Central America. Therefore, QPM seed promotion and distribution to farmers would have a high probability of success in El Salvador.

Concluding Remarks

Briefly stated, the key factors determining the potential of QPM as an animal feed in a country are: 1) the size and sophistication of the pig sector and its use of commercial feed rations; 2) the size of the price premium required to provide incentives for QPM production; and 3) the price of soybean meal and other protein sources, especially synthetic lysine. Other factors influencing the potential for a QPM industry are an active QPM breeding program, the conditions for rapidly developing locally adapted QPM varieties and hybrids, and effective promotion and diffusion of available materials.

An evaluation of the status of the feed industry with regard to size, feed ingredients used, and ingredient prices, combined with a careful economic analysis, is necessary for estimating the potential of QPM as a feed ingredient in any country. The essential condition is a large and advanced pig feed industry and the potential for integrating maize with feed or pig production, so that the problem of distinguishing QPM from other types of maize is reduced.

The main implications for QPM research include the need to develop QPM cultivars with better husk cover and to identify easy methods (especially a genetic marker) for distinguishing QPM from regular maize. The development of QPM inbred lines that can be tested rapidly for adaptation in developing countries should also be a priority, especially for countries with the greatest potential to use QPM in the feed industry. Maintenance of seed purity is also important as the Opaque-2 gene is recessive and can be lost easily if contamination occurs; therefore, a timely and effective seed delivery system is important. Finally, before the decision is taken to embark on QPM research, the method developed in this study can be used, with only small modifications to reflect local conditions, to estimate the potential for QPM as a feed ingredient in a particular country or region.

Appendix A

Linear Programming Models for Starter Pig Rations, Brazil and El Salvador

```
$TITLE    LP for optimal feed ration for starter pigs, BRAZIL;
$offdigit; $offupper; $offsymxref offsymlist; $offuellist offuelxref
option limrow = 0, limcol = 0, sysout = off, solprint = off;

sets
r activities (ingredients)
/rmze, qpmz, cotm, soym, mzgl, whtm, mebm, ccal, caph, lsne, meth, voil, salt, vita,
mine/;

s nutrients necessary for pigs
/meen, prot, lisi, meti, mecy, trip, thre, argi, isol, leuc, vali, phen, calc, diph/;

t stages of growth for pigs (by weight in kg)
/01t15, 15t30, 30t60, 60t100, gest, lact/;

parameters
price(r) price of ingredients (US $ per kg);
/rmze 0.120, cotm 0.180, mzgl 0.280, whtm 0.100, mebm 0.280, ccal 0.050, caph 0.250,
lsne 3.000, meth 3.250, voil 0.650, salt 0.090, vita 3.470, mine 0.430/;
* setting the price of QPM and Soybean Meal;
price('qpmz') = price('rmze')*1.00; price('soym') = price('rmze')*2.00;
```

Table: minrqnut(s,t) minimum required nutrients for pigs by growth stage (kg)

*	01t15	15t30	30t60	60t100	gest	lact
meen	3.500	3.400	3.300	3.300	3.300	3.350
prot	21.00	17.60	15.00	13.10	12.06	15.33
lisi	1.043	0.860	0.686	0.591	0.444	0.667
meti	0.333	0.275	0.218	0.188	0.128	0.184
mecy	0.665	0.550	0.436	0.376	0.256	0.369
trip	0.175	0.143	0.116	0.099	0.083	0.133
thre	0.658	0.544	0.432	0.373	0.344	0.500
argi	0.333	0.275	0.218	0.188	0.000	0.400
isol	0.704	0.578	0.462	0.399	0.389	0.413
leuc	0.921	0.758	0.604	0.518	0.494	0.793
vali	0.690	0.571	0.452	0.389	0.472	0.604
phen	0.448	0.371	0.294	0.254	0.294	0.422
calc	0.882	0.751	0.673	0.607	0.756	0.838
diph	0.191	0.169	0.154	0.142	0.183	0.173

*

Table: maxrqnut(s,t) maximum required nutrients for pigs by growth stage (kg)

	01t15	15t30	30t60	60t100	gest	lact
meen	3.600	3.500	3.400	3.400	3.400	3.450
prot	23.00	19.60	17.00	15.10	14.06	17.33
calc	0.932	0.801	0.723	0.657	0.806	0.888

* Note: These two tables contain minimum and maximum nutritional requirements for all growth stages.

Table: minnutcon(s,r) nutrient content of each ingredient for min constraints

	rmze	qpmz	cotm	soym	mzgl	whtm	mebm	ccal	caph	lsne	meth	voil
meen	3.430	3.773	2.105	3.081	4.219	1.992	2.003	0	0	0	0	7.674
prot	9.70	10.7	39.3	45.6	60.9	15.3	45.2	0	0	0	0	0
lisi	0.24	0.42	1.54	2.87	1.00	0.57	2.28	0	0	78	0	0
meti	0.15	0.16	0.53	0.65	1.62	0.22	0.54	0	0	0	98	0
mecy	0.30	0.34	1.09	1.34	2.70	0.52	0.97	0	0	0	98	0
trip	0.06	0.11	0.53	0.67	0.28	0.24	0.24	0	0	0	0	0
thre	0.33	0.37	1.26	1.78	2.08	0.48	1.47	0	0	0	0	0
argi	0.39	0.56	4.27	3.29	1.97	0.99	3.26	0	0	0	0	0
isol	0.30	0.28	1.23	2.18	2.43	0.5	1.32	0	0	0	0	0
leuc	1.14	0.85	2.33	3.59	10.04	0.96	2.66	0	0	0	0	0
vali	0.43	0.46	1.76	2.12	2.95	0.69	2.11	0	0	0	0	0
phen	0.45	0.40	2.12	2.20	3.80	0.59	1.53	0	0	0	0	0
calc	0.02	0.02	0.26	0.36	0.06	0.12	11.6	38	20	0	0	0
diph	0.09	0.09	0.31	0.18	0.12	0.29	5.4	0	18.5	0	0	0;

Table maxnutcon(s,r) nutrient content of each ingredient for max constraints

	rmze	qpmz	cotm	soym	mzgl	whtm	mebm	ccal	caph	lsne	meth	voil
meen	3.430	3.773	2.105	3.081	4.219	1.992	2.003	0	0	0	0	7.674
prot	9.70	10.7	39.3	45.6	60.9	15.3	45.2	0	0	0	0	0
calc	0.02	0.02	0.26	0.36	0.06	0.12	11.6	38	20	0	0	0

```
variables
   mincost        cost of feed
   optingr(r)     optimal level of ingredients
positive variables optingr(r);

equations
   objective          objective function
   minnutcnts(s)      minimum requirement constraints
   maxnutcnts(s)      maximum requirement constraints
   total              total ingredients equal 100 percent;
```

```
objective..        mincost =e= sum(r,price(r)*optingr(r));
minnutcnts(s)..    sum(r,optingr(r)*minnutcon(s,r)) =g= minrqnut(s,"01t15");
maxnutcnts(s)..    sum(r,optingr(r)*maxnutcon(s,r)) =l= maxrqnut(s,"01t15");
total..            sum(r,optingr(r)) =e= 1;

* some ingredient limits:
optingr.lo('salt')  =  .004; optingr.up('salt') = .004;
optingr.lo('vita')  =  .001; optingr.up('vita') = .001;
optingr.lo('mine')  =  .001; optingr.up('mine') = .001;

parameters
   costdoll(*,*)        minimum cost of ration (US doll per MT)
   costdiff(*,*)        % and Dollr cost difference of rations with and without QPM
   eqnlevl1(s,*,*)      nutritional content of ration (kg per MT)
   eqnmrgn1(s,*,*)      marginal values of nutrient constraints (dolls per kg)
   optlevl1(r,*,*)      optimal ration composition (kg)
   optmrgn1(r,*,*)      marginal value of ingredients (dolls per kg);
   eqnlevl1(s,'01t15','minreq') = minrqnut(s,'01t15');

model pigs01t15 /all/;
$title run for 01t15 wk pigs with all ingredients;
solve pigs01t15 using lp minimizing mincost;
costdoll('01t15','qpmzsi')        =  mincost.l*1000;
eqnlevl1(s,'01t15','qpmzsi')      =  minnutcnts.l(s);
eqnmrgn1(s,'01t15','qpmzsi')      =  minnutcnts.m(s);
optlevl1(r,'01t15','qpmzsi')      =  optingr.l(r)*1000;
optmrgn1(r,'01t15','qpmzsi')      =  optingr.m(r);

$title  model run for 01t15 week pigs with no QPM;
optingr.up('qpmz') = 0;
solve pigs01t15 using lp minimizing mincost;
costdoll('01t15','qpmzno')        =  mincost.l*1000;
eqnlevl1(s,'01t15','qpmzno')      =  minnutcnts.l(s);
eqnmrgn1(s,'01t15','qpmzno')      =  minnutcnts.m(s);
optlevl1(r,'01t15','qpmzno')      =  optingr.l(r)*1000;
optmrgn1(r,'01t15','qpmzno')      =  optingr.m(r);
costdiff('01t15','percent')       =  100*(1 - costdoll('01t15','qpmzsi') /
costdoll('01t15','qpmzno'));
costdiff('01t15','dollars')       =  costdoll('01t15','qpmzno')- costdoll('01t15','qpmzsi');

display costdoll, costdiff, optlevl1, eqnlevl1, eqnmrgn1, optmrgn1,
********** END OF PROGRAM FOR STARTER PIGS IN BRAZIL ************;
```

```
$TITLE    LP for optimal feed ration for starter pigs, EL SALVADOR;
$offdigit; $offupper; $offsymxref offsymlist; $offuellist offuelxref
option limrow = 0, limcol = 0, sysout = off, solprint = off;

sets
r activities (ingredients)
/rmze, qpmz, sorg, soym, whtm, mzgl, mebm,
 ccal, caph, sebo, mols, lsne, meth, salt, vita, mine/

s nutrients necessary for pigs
/meen, prot, lisi, meti, mecy, trip, thre, argi, isol, leuc, vali, hist, phen, phty, calc, diph/

t stages of growth for pigs (by weight in kg)
/01t15, 15t30, 30t60, 60t100, gest, lact/;

parameters
price(r) price of ingredients (US$ per kg)
/rmze 0.120, whtm 0.100, mzgl 0.280, mebm 0.280, ccal 0.050, caph 0.250, sebo 0.387,
 mols 0.060, lsne 3.000, meth 3.250, salt 0.090, vita 3.470, mine 0.430/;
* setting the price of QPM, Soybean Meal and SORG;
price('qpmz') = price('rmze')*1.00; price('sorg') = price('rmze')*0.95;
price('soym') = price('rmze')*2.00;
```

Table: minrqnut(s,t) minimum required nutrients for pigs by growth stage (kg)

*	01t15	15t30	30t60	60t100	gest	lact
meen	3.500	3.400	3.300	3.300	3.300	3.350
prot	21.00	17.60	15.00	13.10	12.06	15.33
lisi	1.043	0.860	0.686	0.591	0.444	0.667
meti	0.333	0.275	0.218	0.188	0.128	0.184
mecy	0.665	0.550	0.436	0.376	0.256	0.369
trip	0.175	0.143	0.116	0.099	0.083	0.133
thre	0.658	0.544	0.432	0.373	0.344	0.500
argi	0.333	0.275	0.218	0.188	0.000	0.400
isol	0.704	0.578	0.462	0.399	0.389	0.413
leuc	0.921	0.758	0.604	0.518	0.494	0.793
vali	0.690	0.571	0.452	0.389	0.472	0.604
phen	0.448	0.371	0.294	0.254	0.294	0.422
calc	0.882	0.751	0.673	0.607	0.756	0.838
diph	0.191	0.169	0.154	0.142	0.183	0.173

Table: maxrqnut(s,t) maximum required nutrients for pigs by growth stage (kg)

*	01t15	15t30	30t60	60t100	gest	lact
meen	3.600	3.500	3.400	3.400	3.400	3.450
prot	23.00	19.60	17.00	15.10	14.06	17.33
calc	0.932	0.801	0.723	0.657	0.806	0.888

* Note: These two tables contain minimum and maximum nutritional requirements for all growth stages.

Table: minnutcon(s,r) nutrient content of each ingredient for min constraints

*	rmze	qpmz	sorg	soym	mzgl	whtm	mebm	ccal	caph	lsne	meth	sebo	mols
meen	3.430	3.773	3.278	3.081	4.219	1.992	2.003	0	0	0	0	8.059	2.374
prot	9.70	10.7	8.52	45.6	60.9	15.3	45.2	0	0	0	0	0	3.01
lisi	0.24	0.42	0.20	2.87	1.00	0.57	2.28	0	0	78	0	0	0
meti	0.15	0.16	0.13	0.65	1.62	0.22	0.54	0	0	0	98	0	0
mecy	0.30	0.34	0.28	1.34	2.70	0.52	0.97	0	0	0	98	0	0
trip	0.06	0.11	0.09	0.67	0.28	0.24	0.24	0	0	0	0	0	0
thre	0.33	0.37	0.23	1.78	2.08	0.48	1.47	0	0	0	0	0	0
argi	0.39	0.56	0.30	3.29	1.97	0.99	3.26	0	0	0	0	0	0
isol	0.30	0.28	0.29	2.18	2.43	0.50	1.32	0	0	0	0	0	0
leuc	1.14	0.85	0.86	3.59	10.04	0.96	2.66	0	0	0	0	0	0
vali	0.43	0.46	0.35	2.12	2.95	0.69	2.11	0	0	0	0	0	0
phen	0.45	0.40	0.32	2.20	3.80	0.59	1.53	0	0	0	0	0	0
calc	0.02	0.02	0.02	0.36	0.06	0.12	11.6	38	20	0	0	0	0.78
diph	0.09	0.09	0.07	0.18	0.12	0.29	5.40	0	18.5	0	0	0	0.03;

Table: maxnutcon(s,r) nutrient content of each ingredient for max constraints

*	rmze	qpmz	sorg	soym	mzgl	whtm	mebm	ccal	caph	lsne	meth	sebo	mols
meen	3.430	3.773	3.278	3.081	4.219	1.992	2.003	0	0	0	0	8.059	2.374
prot	9.70	10.7	8.52	45.6	60.9	15.3	45.2	0	0	0	0	0	3.01
calc	0.02	0.02	0.02	0.36	0.06	0.12	11.6	38	20	0	0	0	0.78

```
variables
mincost          ost of feed
optingr(r)       optimal level of ingredients
positive variables optingr(r);

equations
   objective        objective function
   minnutcnts(s)    minimum requirement constraints
   maxnutcnts(s)    maximum requirement constraints
   total            total ingredients equal 100 percent;

objective..        mincost =e= sum(r,price(r)*optingr(r));
minnutcnts(s)..    sum(r,optingr(r)*minnutcon(s,r))=g= minrqnut(s,"01t15");
maxnutcnts(s)..    sum(r,optingr(r)*maxnutcon(s,r))=l= maxrqnut(s,"01t15");
total..            sum(r,optingr(r)) =e= 1;

* some ingredient limits:
   optingr.up('sebo')  = .05; optingr.up('mols') = .10;
   optingr.lo('salt')  = .004; optingr.up('salt') = .004;
   optingr.lo('vita')  = .001; optingr.up('vita') = .001;
   optingr.lo('mine')  = .001; optingr.up('mine') = .001;
```

```
parameters
   costdoll(*,*)        minimum cost of ration (US doll per MT)
   costdiff(*,*)        % and doll cost difference of rations with and without QPM
   eqnlevl1(s,*,*)      nutritional content of ration (kg per MT)
   eqnmrgn1(s,*,*)      marginal values of nutrient constraints (dolls per kg)
   optlevl1(r,*,*)      optimal ration composition (kg)
   optmrgn1(r,*,*)      marginal value of ingredients (dolls per kg);
   eqnlevl1(s,'01t15','minreq') = minrqnut(s,'01t15');

model pigs01t15 /all/;
$title run for 01t15 wk pigs  with all ingredients;
solve pigs01t15 using lp minimizing mincost;
costdoll('01t15','qpmzsi')        =  mincost.l*1000;
eqnlevl1(s,'01t15','qpmzsi')      =  minnutcnts.l(s);
eqnmrgn1(s,'01t15','qpmzsi')      =  minnutcnts.m(s);
optlevl1(r,'01t15','qpmzsi')      =  optingr.l(r)*1000;
optmrgn1(r,'01t15','qpmzsi')      =  optingr.m(r);

$title  model run for 01t15 week pigs with no QPM;
optingr.up('qpmz') = 0;
solve pigs01t15 using lp minimizing mincost;
costdoll('01t15','qpmzno')        =  mincost.l*1000;
eqnlevl1(s,'01t15','qpmzno')      =  minnutcnts.l(s);
eqnmrgn1(s,'01t15','qpmzno')      =  minnutcnts.m(s);
optlevl1(r,'01t15','qpmzno')      =  optingr.l(r)*1000;
optmrgn1(r,'01t15','qpmzno')      =  optingr.m(r);
costdiff('01t15','percent')       =  100*(1 - costdoll('01t15','qpmzsi') /
costdoll('01t15','qpmzno'));
costdiff('01t15','dollars')       =  costdoll('01t15','qpmzno')- costdoll('01t15','qpmzsi');

display costdoll, costdiff, optlevl1, eqnlevl1, eqnmrgn1, optmrgn1;
************ END OF PROGRAM FOR STARTER PIGS IN EL SALVADOR ***********;
```

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