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MARKET POTENTIAL FOR PROTEIN CONCENTRATE PRODUCED FROM FERMENTATION OF SPENT SULFITE LIQUOR

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SUMMARY AND CONCLUSIONS

Disposition of spent sulfite liquor from paper and pulp mills has been the subject of research for many years. Utilization of the liquor through commercial production of torula yeast and of bacterial cell concentrate in laboratory studies has been successful in reducing the biochemical oxygen demand of the spent sulfite liquor. The objective of this study was to conduct a preliminary investigation of the potential market value of torula yeast and bacterial concentrate, if either of these products were to be produced in the Pacific Northwest.

Small quantities of torula yeast or bacterial concentrate could be used in poultry or livestock rations for their vitamin content or unidentified growth factors at prices of 8 to 10 cents per pound. However, any large-scale production would be dependent upon their utilization as a high-protein feed supplement.

Total inshipments of high-protein feedstuffs into the Pacific Coast area summed to the equivalent of about 117,000 tons of protein in 1956. Maximum possible annual production of bacterial cell concentrate would be equivalent to 81,000 tons of protein, or less than 69% of the 1956 Pacific Coast protein deficit. Since the nature of the effluent disposal problems of the sulfite mills in this region vary widely, it is unlikely that a program of torula yeast or bacterial concentrate production would prove equally attractive to all mills. It is believed that the total possible production from a substantial number of mills could be readily sold as high-protein feed supplement in Washington, Oregon, and California.

Feeding values for torula yeast and bacterial concentrate have been estimated under current price conditions of the Pacific Northwest by means of linear programming analysis. These predicted feeding values average slightly over 4 cents per pound for torula yeast and over 5 cents per pound for bacterial concentrate. If present prices of other feedstuffs remain fairly stable, as now seems probable, torula yeast could be sold by the potential pulp mill producer at a price of 3.5 to 4 cents per pound, depending upon the quantity marketed. Similarly, bacterial cell concentrate should sell for at least 4.5 to 5 cents per pound.

DISPOSAL AND UTILIZATION POSSIBILITIES FOR SPENT SULFITE LIQUOR

During the past 70 years, the disposition of spent liquors from the sulfite pulp industry has been the subject of a tremendous volume of research. The pulp industry along with public and private research centers have spent millions of dollars on the spent liquor problem. This study was undertaken in cooperation with the National Council for Stream Improvement (of the Pulp, Paper and Paperboard Industries), Inc. to evaluate the market potential for the more promising fermentation products which could be produced from spent sulfite liquor. Information from a study of this nature will be useful in determining whether large-scale pilot plant and animal feeding studies are justified at this time.

In the broadest sense, two general lines of approach have been used in research related to the disposition of spent sulfite liquor: (1) treatment of the liquor to minimize the deoxygenating effect of its wood sugar content on receiving streams, and (2) utilization of raw materials present in the spent liquor.

The original practice, which has been continued in most cases, was to discharge the spent liquor as produced, with no pretreatment, into the receiving waters. Modifications using the method of impoundment and controlled discharge to streams have been developed and found applicable in numerous situations.

Where large volumes of dilution water are available, some mills have been able to build special discharge lines to achieve maximum dilution.[1/] This procedure has been followed by a Florida plant which pipes spent liquor five miles into the Gulf Stream, and at Camas and Vancouver, Washington, where spent liquor is distributed in the central currents of the Columbia River.

1/ G. C. Inskeep, A. J. Wiley, J. M. Holderby, and L. P. Hughes, "Food Yeast from Sulfite Liquor," Industrial and Engineering Chemistry, Vol. 43, No. 8, August, 1951, pp. 1702-1711.

A primary objective of past research has been stream improvement, but there is a growing interest in the utilization of this great amount of potential raw material. Investigations have resulted in processes utilizing the liquor itself or its components, such as lignin. Vanillin, oxalic acid, tanning material, road binders, dispersing agents in concrete, alcohol by fermentation, and other products have been made from sulfite liquor. However, most of these by-products would provide an outlet for only a very small portion of the total spent liquor produced each year.

Where magnesium base sulfite pulping is employed, chemical and heat recovery by evaporation and burning of the spent liquor has proven feasible.[1] By this procedure, the organic fraction containing the lignin and sugar is destroyed by combustion, and the primary combustion products (magnesium oxide and sulfur dioxide) are recovered for reuse as pulping agents. Four mills have employed this process, with a fifth under construction. Research is also under way on other sulfite pulping recovery processes which may further reduce the magnitude of the spent liquor disposal problem.

YEAST AND BACTERIAL PRODUCTS FROM SPENT
SULFITE LIQUOR

Utilization of spent sulfite liquor for the production of fodder yeast is not new. Germany produced an estimated 75,000 tons of yeast from spent sulfite liquor in 1944, and Sweden has also utilized spent sulfite liquor in this way.

Information regarding the German sulfite liquor yeast plants stimulated interest in the United States following World War II. Yeast from spent sulfite liquor was first produced in commercial quantities in this country by the Lake States Yeast Corporation, Rhinelander, Wisconsin.

1/ W. Q. Hull, R. E. Baker, and C. E. Rogers. "Magnesia-Base Sulfite Pulping," Industrial and Engineering Chemistry, Vol. 43, No. 11, November, 1951, pp. 2424-2435.

Torulopsis utilis is the yeast organism which has usually been grown on sulfite waste liquor. It utilizes much of the sugars contained in the liquor and has generally been well adapted for growth in the liquor.

A commonly used measure of pollutional strength of waste products is the biochemical oxygen demand (BOD). When yeast have been grown on the spent sulfite liquor, BOD reductions have ranged from 50% to 65%. Thus, production of yeast may be a reasonably effective pollutional abatement measure where effluent oxygen demand constitutes a problem.

Even greater BOD reductions of 80% or more have been achieved by using a process employing a mixed bacterial culture which has been developed by the National Council for Stream Improvement at the Engineering Experiment Station at Oregon State College.1/ This process, an aerobic fermentation, not only effected high BOD reductions but also produced high yields of bacterial concentrate having a protein content of 66% to 70%. Because of this protein content and the relatively high cell yield, a few preliminary tests were made of the cell material as a high protein supplement.

Since either yeast or bacterial products would provide a potential high-quality, locally produced feed supplement for the livestock of the Pacific Northwest, a current appraisal of the value of yeast and bacteria as feed supplements was needed. (Early studies of the economic possibilities of torula yeast production in the Pacific Northwest were published ten years ago.)2/ 3/

1/ Herman R. Amberg, "Bacterial Fermentation of Spent Sulfite Liquor for the Production of Protein Concentrate Animal Feed Supplement," Eng. Exp. Sta. Bul. No. 38, Oregon State College, Corvallis, Ore., October, 1956.

2/ Margaret L. Schleef, "The Economics of Fodder Yeast from Sulfite Waste Liquor," Economic and Business Studies Bul. No. 7, The State College of Washington, Pullman, Wash., September, 1948.

3/ National Council for Stream Improvement, "Sulfite Waste Research Report-- Fodder Yeast Production from Sulfite Liquor," Tech. Bul. No. 8, April, 1947.

NUTRITIVE VALUE OF TORULA YEAST AND BACTERIAL CONCENTRATE

A great deal more is known about the feeding value of torula yeast than is known about bacterial cell concentrate since only a few preliminary feeding tests were made with the bacterial concentrate. These preliminary trials indicate that similar possibilities and limitations exist for the cell concentrate as for torula yeast. For lack of more specific information, a similar type of feeding response will be assumed for bacterial concentrate as has been found for torula yeast.

Crude protein of torula yeast averages around 46%, and fiber is about 2.5%. While these percentages are fairly stable for torula yeast, the protein content of bacterial cell concentrate can be made to range from 50% to 70%, depending upon the number of washings, with a corresponding decrease in yield.

Quality of torula yeast and bacterial cell protein appears to be good. Digestibility of torula yeast is estimated to be about 86%, which is comparable to the digestibility of most other high-protein sources.[1/] Amino acid analysis for bacterial cell concentrate and torula yeast compare favorably with other protein sources.[2/] However, feeding tests at high levels seem to show a deficiency of methionine and possibly isoleucine or other essential amino acids.

Torula yeast and bacterial concentrate are excellent sources of most of the essential vitamins, and are superior in this respect to soybean meal, fish meal, and other oilseed meals.[3/] However, the cost of vitamin supplement has declined greatly in recent years and the natural vitamin content of feeds receives much less attention. The total cost for vitamins per ton of broiler feed is now less than $3.[4/]

1/ F. B. Morrison, Feeds and Feeding, 21st Ed., The Morrison Publishing Co., Ithaca, N. Y., 1951, p. 1069.

2/ H. R. Amberg, op. cit., pp. 31-32.

3/ Amberg, op. cit., pp. 29-31.

4/ R. F. Hutton, G. A. King, R. V. Boucher, "A Least-Cost Broiler Feed Formula Method of Derivation," Prodn. Res. Report No. 20, A.R.S. and A.M.S., U.S.D.A., Wash., D. C., May, 1958, p. 4.

Several feeding tests for specific classes of poultry and livestock have been made. One of the most thorough feeding trials for poultry has been reported by Ringrose.[1] He concluded that a combination of torula yeast and soybean meal as the protein supplement gave better growth of young chickens than did torula yeast alone. Also, 4% added fish meal significantly increased growth for the torula yeast-soybean meal combination. The addition of 0.25% choline chloride was also beneficial. He further concluded that torula yeast should not exceed 10% to 12% unless pelleted to prevent pressure necrosis.

For laying pullets producing hatching eggs, torula yeast was satisfactory as the only protein supplement. Thus, torula yeast (and probably also bacterial cell concentrate) could provide a substantial portion of the ration for poultry on the Pacific Coast, if it could be produced and sold for a price comparable to its feeding value.

Feeding tests with dairy cows lasting 26 days indicated that torula yeast was apparently a satisfactory protein supplement when fed in combination with other feed. In this experiment it was fed as a 50-50 mixture with beet pulp.[2]

Bacterial cell concentrate has also been tried with cattle, being fed 35 days to four male calves, two Holsteins, and two Jerseys.[3] The bacterial cell concentrate was incorporated into the calf meal at the 4% level, and increased an additional 2% every five days until the 10% level was reached. The calves were then maintained at the 10% level for a period of 20 days. The bacterial concentrate fed in this manner appeared to be palatable at the 10% level. Average daily gain was 1.11 pounds.

1/ R. C. Ringrose, "Nutritive Properties of Torula Yeast for Poultry," Poultry Science, Vol. XXVIII, January, 1949, pp. 75-83.

2/ E. G. Ritzman, "Wood Yeast for Animal Feed," Northeastern Wood Utilization Council Bul. No. 12, P. O. Box 1577, New Haven 6, Conn., November, 1946, pp. 27 to 40.

3/ R. C. Sprowls and I. R. Jones, Report by Department of Dairying on Feeding "Bacto-Protein," Oregon State College, Corvallis, Oregon, January 17, 1956, 2 leafs.

From the preceding research and other findings it was concluded that torula yeast and bacterial concentrate would likely be satisfactory as major sources of protein for the rations of poultry and livestock. Of course, additional research would be needed to more accurately assess the feeding value of bacterial concentrate and torula yeast, if commercial quantities were to be produced and fed as protein supplement.

THE PROTEIN DEFICIT FOR THE PACIFIC COAST

Since the largest market for yeast or bacterial concentrate would be in the field of high-protein supplements, the deficit in proteins for livestock on the Pacific Coast is very important in estimating the market potential for yeast or bacterial concentrate. Some idea of this deficit can be obtained from Table 1, where a 1% sample of net inshipments in the year 1956 are presented. According to these figures, about 280,000 more tons of high-protein material were shipped into California, Oregon, and Washington than were shipped out of these states. The net inshipments for 1955 show an even greater deficit of 359,000 tons.

These figures indicate a deficit greater than the entire potential production of yeast or bacterial cells. For the Pacific Northwest, the most recent

Table 1. One-Percent Sample of Net Inshipments of Various High-Protein Supplement Sources to the Pacific Coast in 1956[1/]

Net Imports to State	Commodity (Tons)					Total for All Commodities
	Soybeans	Soybean Oil Cake, Meal	Cotton-seed	Cottonseed Cake, Meal	Veg. Oil Cake	
California	581	1013	106	-100	-30	1570
Oregon	--	281	--	70	--	351
Washington	--	846	--	--	30	876
Total	581	2140	106	-30	0	2797

1/ Summarized from Carload Waybill Statistics, 1956. State-to-State Distribution of Products of Agriculture Traffic and Revenue. One-percent sample of terminations in the year 1956. U. S. Interstate Commerce Commission. Bureau of Transport Economics and Statistics, Wash., D. C., September, 1957.

pulping capacity data from Lockwoods Directory of the Paper and Allied Trades, 1957, is tabulated below, omitting those mills which are already heavily committed to some alternative disposal method.[1/]

Location of Mills	Tons Pulp per Day	Tons Torula Yeast per Day	Tons Bacterial Cells per Day[2/]
Oregon	725	63.4	72.5
Washington	2500	218.8	250.0
Total Tonnage	3225	282.2	322.5

From the preceding data, a total annual production of bacterial cell material of 116,000 tons would be forthcoming under a 360-day operating schedule. About 102,000 tons of torula yeast would be the maximum annual production. These figures can be considered as an upper limit on the production potential. However, a larger quantity of bacterial concentrate could be produced, but at a lower protein content. Thus, a total annual production of 135,000 tons could be had at 60% protein content. This quantity of production would be equivalent to 81,000 tons of protein. Total torula yeast production would be equivalent to about 48,000 tons of protein.

Converting the figures in Table 1 to tons of protein, the total protein deficit was about 117,000 tons. Thus, 69% of the 1956 protein deficit of the Pacific Coast could have theoretically been supplied by production of bacterial cell concentrate. It is doubtful, of course, that such a quantity of production would ever be realized since the effluent disposal problems of sulfite mills vary considerably.

1/ This information was obtained through private correspondence with Dr. Isaiah Gellman, West Coast Regional Engineer, National Council for Stream Improvement.

2/ These figures assume 70% protein content and 80% initial spent sulfite liquor collection efficiency.

POSSIBLE FUTURE TRENDS FOR THE PACIFIC COAST PROTEIN SITUATION

Although the Pacific Coast is now a protein-deficit area, there is always the possibility that this situation could change. Such a change would have a definite impact on the feasibility of utilizing spent sulfite liquor for protein production since the price of soybean meal, the most important supplement shipped to the Pacific Coast, includes a freight charge of about $30 per ton. If soybeans or other high-protein products were produced locally in sufficient quantity to erase the freight differential, the possible selling price for torula yeast or bacterial concentrate would be greatly lessened.

Likelihood of Increased Production of High-Protein Crops

One crop in which there has been considerable interest in the Pacific Northwest is soybeans. A great deal of experimentation has been and continues to be carried on in the Columbia Basin in Washington. Yet, despite the favorable marketing situation for oil and meal, it does not appear very likely that there will be a large production in this area.[1] It has been difficult to harvest soybeans because of the mild, wet fall weather. Of course, there is always a chance that earlier maturing varieties or other technological innovations, such as defoliants, will make soybeans more profitable. At present, however, it does not appear that soybeans will compete favorably with other crop alternatives.

Other high-protein crops have also received considerable attention in the Pacific Northwest. For example, a number of experiments have been conducted with safflower at the Pendleton Branch Experiment Station. Farmers in eastern

1/ C. E. Nelson, A. H. Harrington, and J. C. Gifford. "How About Soybeans for the Columbia Basin?" Wash. Agr. Exp. Sta. Circ. 250, Pullman, Wash., April, 1954, pp. 1-9.

Oregon have also tried safflower on a field basis. Again, despite this interest, it does not currently seem likely that there will be any great production in this area since present crop alternatives appear to be equally or more profitable.

Production of dry peas, a high-protein crop, could be increased in the Pacific Northwest. However, there are no indications of any great surge of output.

In summary, it does not appear likely that there will be any great increase of high-protein concentrate crop production in the Pacific Northwest.

Anticipated Changes in Demand for High-Protein Supplement

Increased demand for protein supplement would be expected with an expansion of livestock production on the Pacific Coast. Two main factors which are cited as encouraging an expansion of livestock are (1) increased availability of feed, and (2) a rapid population growth.[1]

Population in the three Pacific Coast states in 1956 was 186% of the population in 1939. For California, the 1956 figure was almost double the 1939 figure. For the same period, population for the United States as a whole increased by only 28%.

Greater need for livestock to convert feed grains and forages has been given added importance with the diversions from cash crops forced by government programs within the past five years. As acreages of wheat, cotton, rice, and corn have been reduced, there has been a corresponding increase in production of feed crops. Comparing 1955 with 1953 at the national level shows that a 29-million acre reduction of crops under allotment was accompanied by an

[1] These factors recently have been analyzed by Gordon R. Sitton. "Livestock in the Agricultural Adjustment Picture of the Western Region." To be published in the Proceedings of the Western Farm Management Research Committee, presented at Washington State College, Pullman, Wash., August, 1958.

increase of about 27 million acres of feed crops.

In recent years barley has been the most important feed grain produced in the 11 western states. Production in 1954 was 159% of that in the preceding year, and 1957 production was 194% of that in 1953, before allotments were imposed on the major cash crops. Production of oats has remained nearly constant during this period, but the production of both corn and grain sorghums has increased substantially, adding to the total quantity of feed grains available in the western states.

Despite the great increase in availability of feed grains, there has not, as yet, been a comparable increase in livestock for the Pacific Coast area. Average number of grain-consuming livestock units for 1954, 1955, and 1956 was only 102% of the preceding three-year average. However, increased feed supplies have led to recommendations that more meat should be produced in the western states to replace part of the meat now shipped into the area. Such an expansion may take place after a time lag that is expected to occur with such developments.

Although there has not been a marked expansion of livestock production in the West Coast area, conditions do appear to be increasingly favorable for such a development. This fact coupled with the small liklihood of any great increase in high-protein concentrate crop production in the area points to a long-run deficit of protein supplement on the West Coast.

ECONOMIC EVALUATION OF TORULA YEAST AND BACTERIAL CONCENTRATE AS PROTEIN SUPPLEMENTS

Small quantities of dried yeast are often added to the rations of young chickens or turkeys as a tonic or for unidentified growth factors which might be available. Since only a few pounds are added per ton of feed, some feed manufacturers have been willing to pay relatively high prices per pound for such a product. For example, the price of brewers' dried yeast has recently ranged from 8 to 12 cents per pound.

Torula yeast or bacterial cell concentrate might be produced for a similar purpose. However, really large quantities of production would be difficult to move at 8 to 10 cents per pound. Mass production would have to be utilized primarily for its protein value. For this reason, the following economic analysis was made to measure the value of torula yeast and bacterial cell concentrate under present price and feeding conditions.

Predicted Value of Torula Yeast in Poultry and Livestock Rations

Methods employed for evaluation consist primarily of meeting certain ration specifications most cheaply with existing feed sources, then calculating the prices at which it would pay to introduce torula yeast or bacterial cell concentrate into the ration. Mathematical details are presented in the Appendix. The linear programming model used is essentially an adaptation of a model recommended for use by the feed industry.[1]

Since the precise substitution values in terms of other protein sources have not been definitely established, especially in the case of bacterial concentrate, a variety of assumptions have been made regarding feeding values. Then, the price has been estimated at which yeast and bacterial concentrate would compete under these different conditions.

First, it is assumed that torula yeast and bacterial concentrate could be used without restriction in the ration. Feeding values obtained under this assumption give the highest expected price for yeast and bacterial concentrate.

The second assumption is that the fermentation products (yeast and bacteria) would have to be used in combination with other plant proteins and could not

1/ R. F. Hutton, G. A. King, and R. V. Boucher. "A Least-Cost Broiler Feed Formula Method of Derivation," Prodn. Res. Report No. 20, A.R.S. and A.M.S. U.S.D.A., Wash., D. C., May, 1958.

exceed 50% by weight of the total protein source mixture. This assumption usually results in somewhat lower predicted prices for torula yeast and bacterial concentrate because of shifts necessitated by ration requirements in the other feed ingredients.

Even more conservative is the third assumption that the yeast or bacterial product could comprise only 50% or less by weight of the high-protein source with 42% or more supplied by plant protein and 8% from fish meal.[1] Because of the relatively higher price for fish meal, this assumption gives the lowest predicted price for torula yeast and bacterial concentrate.

A fourth assumption made for bacterial concentrate was that it would be washed sufficiently to run 70% protein. This assumption was made to compare relative values of 65% and 70% bacterial concentrate.

By the first three preceding assumptions, predicted prices for torula yeast are presented in Table 2. These prices represent "break-even" points. At prices higher than these, it would not pay to feed torula yeast for the particular type of ration. Prices lower than those given in Table 2 would tend to encourage greater consumption.

In looking at the feeding values in Table 2, it can be observed that the different assumptions with regard to the way torula yeast could be fed did not have a great influence on its feeding value, except for the case of one of the layer-breeder rations and for the dairy ration. In most poultry rations, the torula yeast would be worth around $0.04 per pound or $80 per ton under present Pacific Northwest prices (summer, 1958). If used in dairy and beef cattle rations, its value would be around $60 per ton. However, if large quantities of torula yeast were suddenly placed on the market, an inducement price of $5 per

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[1] Cf. R. C. Ringrose, op. cit.

Table 2. Predicted Maximum Feeding Values per Ton for Torula Yeast for Poultry and Livestock Rations Under Pacific Northwest Prices of July, 1958 and for Various Ration Specifications

Specifications for Variable Portion of Mix				Torula Yeast Value Under Various Assumptions		
Variable Portion[1] (Pounds/Ton)	Minimum Protein[2] (Pounds)	Maximum Fiber (Pounds)	Minimum Energy[3]	Fed Without Restriction	Restricted to 50% of Protein Source[4]	Restricted to 50% of Protein Source Plus Fish Meal[5]
Chick starter and broiler rations:				$/Ton	$/Ton	$/Ton
1749[6]	312	70	1670	$86	$84	$82
1673[7]	311	67	1845	79	79	78
Layer-breeder rations:						
1794[8]	261	46	1948	79	79	78
1795[9]	252	75	1679	114	87	86
Turkey starter ration:						
1575[10]	390	72	1475	84	84	82
Dairy rations:						
2000[11]	262	(no limit)	1500	59	47	--
2000[11]	292	(no limit)	1500	59	47	--

1/Total mix was approximately 2000 pounds in all cases.
2/Crude protein except for dairy ration requirements which were in terms of digestible protein.
3/Kilo-calories of productive energy except for dairy ration energy requirements which were in terms of total digestible nutrients.
4/For each pound of torula yeast, 0.5 pound each of soybean meal and cottonseed meal was required.
5/For each pound of torula yeast, 0.42 pound each of soybean meal and cottonseed meal was required, plus 0.16 pound of fish meal.
6/Ration No. 1, 20% protein chick starter. Taken from Ext. Bul. 627, Ore. St. Coll., Corvallis, Ore. Rev. Aug., 1957, p. 8.
7/Ration No. 5, high-energy broiler ration, Ext. Bul. 627.
8/Ration No. 3, high-energy, 15% protein all-mash layer-breeder ration. Taken from Ext. Bul. 744, Ore. St. Coll., Corvallis, Ore., Rev. May, 1957, p. 8.
9/Ration No. 1, 15% protein, all-mash layer-breeder ration.
10/Turkey starter ration taken from Ore. Ag. Exp. Sta. Circ. of Info. 582, Corvallis, Ore., Sept., 1957, p. 9.
11/Adapted from example rations for dairy cows, Feeds and Feeding, 21st Ed., 1948, pp. 1171-1172.

ton below feeding value might be necessary.[1] Also, transportation charges from the producing unit to the feed manufacturer would also have to be deducted from the feeding value. Thus, net price to the producer could dip to $0.035 per pound or $70 per ton if large enough quantities were produced.

Predicted Value of Bacterial Concentrate in Poultry and Livestock Rations

Calculated feeding values for bacterial concentrate in Table 3 generally range from $100 to $110 per ton or $0.050 to $0.055 per pound. Bacterial concentrate feeding values for poultry average about $23 per ton, or over one cent per pound, more than for torula yeast in Table 2. (Average yeast value for poultry was $84 per ton, as compared to $107 per ton for 65% protein bacterial concentrate.) The reason for this higher value for bacterial concentrate results from its higher protein content. However, the value per pound of protein for torula yeast averages $0.0906 per pound, as compared to $0.0826 for bacterial concentrate. This result occurs because less weight and energy would be included with a pound of protein from bacterial concentrate as for a pound of protein from torula yeast.

Feeding value for 70% protein concentrate in Table 3 averages almost $120 per ton when used for poultry rations. Again, although more valuable per pound, its value per pound of protein is $0.0854, as compared to $0.0863 per pound of protein for the 65% cell concentrate. Which protein percentage would be most profitable could readily be determined from cell yield data and washing costs. However, a limitation to comparing feeding values between the 65% and 70% concentrate results because of insufficient experimental data regarding feeding results for the two levels. Changes in assumed levels for these two items would likely change their relative feeding values.

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[1] Feed manufacturers were interviewed during the first phase of the study. According to these interviews, if a feed savings of $0.50 per ton could be obtained by using a new product (while maintaining the same quality) considerable interest would develop in the product. If 200 pounds of new product were used per ton and the product were priced $5 per ton below its actual feeding value, a savings of $0.50 per ton of mixed feed would result from using it.

Table 3. Predicted Maximum Feeding Values per Ton for Bacterial Cell Concentrate for Poultry and Livestock Rations Under Pacific Northwest Prices of July, 1958 and for Various Ration Specifications

Specifications for Variable Portion of Mix				Bacterial Concentrate Values Under Various Assumptions			
Variable Portion1/ (Pounds/Ton)	Minimum Protein2/ (Pounds)	Maximum Fiber (Pounds)	Minimum Energy3/	Fed Without Restriction (65% Protein)	Restricted to 50% of Protein Source4/	Restricted to 50% of Protein Source Plus Fish Meal5/	Fed Without Restriction (70% Protein)
Chick starter and broiler rations:				$/Ton	$/Ton	$/Ton	$/Ton
1749 6/	312	70	1670	$111	$108	$106	$119
1673 7/	311	67	1845	107	107	105	117
Layer-breeder rations:							
1794 8/	261	46	1948	107	107	105	117
1795 9/	252	75	1679	126	99	94	127
Turkey starter ration:							
1575 10/	390	72	1475	110	110	108	118
Dairy rations:							
2000 11/	262	(no limit)	1500	73	61	—	77
2000 11/	292	(no limit)	1500	73	61	—	77

1/Total mix was approximately 2000 pounds in all cases.
2/Crude protein except for dairy ration requirements which were in terms of digestible protein.
3/Kilo-calories of productive energy except for dairy ration energy requirements which were in terms of total digestible nutrients.
4/For each pound of bacterial cell concentrate, 0.5 pound each of soybean meal and cottonseed meal was required.
5/For each pound of bacterial cell concentrate, 0.42 pound each of soybean meal and cottonseed meal was required, plus 0.16 pound of fish meal.
6/Ration No. 1, 20% protein chick starter. Taken from Ext. Bul. 627, Ore. St. Coll., Corvallis, Ore., Rev. Aug., 1957, p. 8.
7/Ration No. 5, high-energy broiler ration, Ext. Bul. 627.
8/Ration No. 3, high-energy, 15% protein all-mash layer-breeder ration. Taken from Ext. Bul. 744, Ore. St. Coll., Corvallis, Ore., Rev. May, 1957, p. 8.
9/Ration No. 1, 15% protein, all-mash layer-breeder ration.
10/Turkey starter ration taken from Ore. Ag. Exp. Sta. Circ. of Info. 582, Corvallis, Ore., Sept., 1957, p. 9.
11/Adapted from example rations for dairy cows, Feeds and Feeding, 21st Ed., 1948, pp. 1171-1172.

Dairy rations in Table 3 gave a much lower value of $61 to $77 per ton for bacterial concentrate. Both torula yeast and bacterial concentrate were worth much less for dairy than poultry rations because the fiber restriction was relaxed for the dairy feed mix and cheaper but higher-fiber protein supplements could enter the solution. (Ruminants are able to utilize high-fiber feeds, whereas poultry and hogs cannot.)

Another reason for the lower feeding values for yeast and cell concentrate used in the dairy ration in Tables 2 and 3 was the rather low cottonseed meal price of $66 per ton which prevailed at the time of the analysis. With a higher cottonseed meal price of $80 per ton, the feeding value of unrestricted torula yeast in the dairy ration jumps to $72 per ton compared to $59 in Table 2. Similarly, bacterial cell concentrate feeding value increases from $73 to $94. Nevertheless, these feeding values are still lower than the values for yeast or bacterial cells used in poultry rations, some of which would also be higher with the higher cottonseed meal price.

Although there is no clear-cut evidence for predicting any great change in grain and protein supplement prices on the Pacific Coast in the near future, such changes could be incorporated into the feeding values for torula yeast and bacterial concentrate in Tables 2 and 3. If all prices, both for feed grains and for high-protein sources, should increase 20%, then the feeding values in Tables 2 and 3 would be increased by 20%. Similarly, if all prices were expected to decline by a certain per cent, the prices for torula yeast and bacterial concentrate in Tables 2 and 3 should be discounted accordingly.

PRICE-QUANTITY RELATIONSHIPS FOR TORULA YEAST AND BACTERIAL CONCENTRATE

Feeding values in Tables 2 and 3 give a good indication of equilibrium price levels for yeast and bacterial concentrate. These prices would be affected by the quantities placed on the market. From Table 1, around 110,000 tons of soybean meal and cake were imported into Washington and Oregon in 1956, or the equivalent of about 50,000 tons of protein. Assuming that only one-half of the soybean meal could be replaced by yeast or bacteria, then about 25,000 tons of protein would be the maximum amount that could be supplied by spent sulfite products in the Pacific Northwest. Another 30% of the 25,000 tons probably should be deducted for buyer resistance and inertia. This would leave the equivalent of either around 38,000 tons of torula yeast or over 27,000 tons of bacterial concentrate which should be readily marketable in Washington and Oregon at F. O. B. prices around $0.04 per pound for torula yeast and $0.05 for bacterial concentrate.

Under the same conservative feeding assumptions, if quantities much greater than the equivalent of 17,000 to 25,000 tons of protein were placed on the market, then much of this production would have to be shipped to California for marketing. It is estimated that the equivalent of about 40,000 tons of protein from spent sulfite liquor products could be readily absorbed by the total Pacific Coast market. This would equal either 86,000 tons of torula yeast or over 60,000 tons of bacterial concentrate of 65% protein content. However, this large quantity of output would be expected to depress the price to the producers by at least $10 per ton or one-half cent per pound because of increased transportation and marketing costs. Thus, producers could expect F. O. B. prices of about 3.5 cents per pound for torula yeast or 4.5 cents for bacterial concentrate.

Further expansion of production much beyond 40,000 tons of protein per year could be expected to result in further price declines, at least under the restrictive assumptions made regarding feeding values. If further experimentation showed that more than 50% of the protein supplement of the ration could efficiently be supplied by torula yeast or bacterial concentrate, then the estimated quantities which could be abserobed by the market at the given prices could be revised upward.

LIMITATIONS AND IMPLICATIONS FOR FUTURE RESEARCH

Although the feeding value estimates for torula yeast and bacterial concentrate were based upon the best available information, numerous gaps exist in this information which would need to be filled by well-designed feeding experiments for more precise evaluations. However, before any major research effort involving a pilot plant could be seriously considered, some idea as to the potential market value of bacterial concentrate and torula yeast was needed.

It is believed that this study has succeeded in estimating this market potential under present market conditions. More precise estimates would require that both torula yeast and bacterial concentrate be fed in large and small quantities to more accurately predict its replacement value for other protein sources.

One important factor which would alter the estimated feeding values for torula yeast and bacterial concentrate would be a general shift in feed prices. As mentioned before, a given percentage change in all feed prices would result in the same percentage change in the predicted torula yeast and bacterial concentrate prices. In Figure 1, the Pacific Northwest soybean meal and corn price indexes have been plotted. This graph shows that most feed prices do tend to go up and down together. Feed prices tended upward for a while after 1949, but then moved back down. By contrast, several industrial indices[1/] have shown a fairly steady climb since 1949. One implication is that if construction costs continue to increase faster than feed crop prices, it would become less and less profitable to build a plant to produce protein supplement from spent sulfite liquor.

[1/] The figures for the Marshall and Stevens Equipment Index for the chemical industry and for paper manufacturing were taken from Chemical Engineering - February 24, 1958, pp. 143-144. The ENR Building Cost and Construction Cost indices were taken from Engineering News Record, March 20, 1958, p. 39.

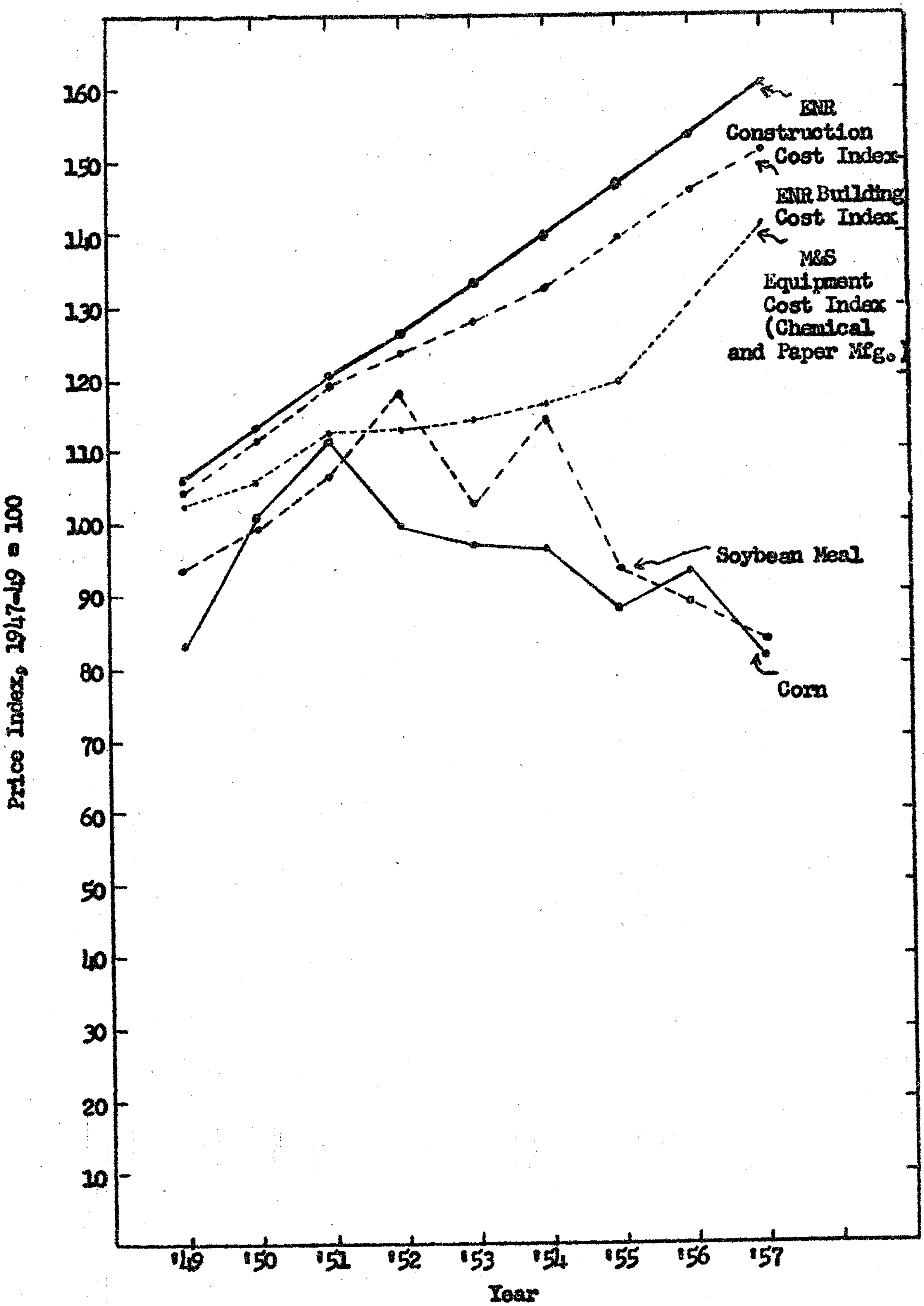

Figure 1. Pacific Northwest Price Movements for Corn and Soybean Meal as Compared to Building, Construction, and Equipment Costs

APPENDIX

LINEAR PROGRAMMING MODEL USED FOR POULTRY RATIONS

As mentioned before, the mathematical model employed is similar to one currently recommended for use by feed manufacturers.[1] Since the total cost of vitamins required is less than $3 per ton if supplied by vitamin supplement, the vitamin content of individual feeds is usually not considered in arriving at a least-cost ration. The most important requirements in the model of Hutton, et al. were for weight, protein, fiber, and energy. Other conditions related to protein-energy balance, amino acids, calcium, and phosphorus.

For our study, the inclusion of the amino-acid conditions did not seem justified because of lack of information regarding the availability of these amino acids, particularly for bacterial cell concentrate. Further feeding experiments would be needed if more refinement were desired in this regard. Calcium and phosphorus were also dropped from our analysis since the change in cost for these minerals would be small as the feed mixture is changed.

To use this model, a typical chick starter ration (20% protein) was selected from Extension Bulletin 627.[2] Certain ingredients assumed to be fixed were 50 pounds of fish meal, 100 pounds of meat and bone meal, 50 pounds of dehydrated alfalfa meal, plus about 51 pounds of minerals, vitamins, and medications. This left about 1749 pounds which could be varied. The protein content of this variable portion ran about 312 pounds, the fiber was close to 70 pounds, and the productive energy was about 1670.5 kilo-calories.

Equation (1) was used to enforce the protein requirement.

1/R. F. Hutton, et al., op. cit.
2/Revised by J. E. Parker and N. L. Bennion. "Chick Brooding and Rearing," Ext. Bul. 627, Ore. St. Coll., Corvallis, Ore., August, 1957, page 8.

$$312 \leq 0.089\ P_6 + 0.09\ P_7 + 0.0895\ P_8 + 0.172\ P_9 + 0\ P_{10} + 0.458\ P_{11} + 0.445\ P_{12} + 0.506\ P_{13} + 0.70\ P_{14} + 0.464\ P_{15} + 0.4545\ P_{16} + 0.4749\ P_{17} + 0.65\ P_{18} + 0.5475\ P_{19} + 0.5679\ P_{20} + 0.70\ P_{21}. \quad (1)$$

In Equation (1), P_6 refers to corn, P_7 to barley, P_8 to a 50-50 mix of corn and barley,[1] P_9 to wheat mixed feed, P_{10} to animal fat, P_{11} to soybean meal, P_{12} to a 50-50 combination of soybean meal and de-gossypolized cottonseed meal, P_{13} to meat and bone scrap, P_{14} to fish meal, P_{15} to torula yeast, P_{16} to 50% torula yeast with 25% each of soybean meal and de-gossypolized cottonseed meal, P_{17} to 50% torula yeast with 21% each of soybean and cottonseed meal plus 8% fish meal, P_{18} to bacterial cell concentrate (65% protein), P_{19} to 50% bacterial concentrate with 25% each of soybean meal and cottonseed meal, P_{20} to 50% bacterial cell concentrate with 21% each of soybean and cottonseed meal plus 8% fish meal, and P_{21} refers to bacterial cell concentrate at the 70% protein level.

The different combinations of torula yeast and bacterial concentrate with the other protein sources allow an estimation of its value under different assumptions. The combinations with added cottonseed, soybean, and fish meal are the most conservative estimates as to the manner in which the fermentation products could be fed. Of course, further feeding experiments would actually be needed to determine which assumptions are most realistic.

To insure that the fiber allowance was not exceeded, Equation (2) specified the following:

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[1] The 50-50 mix is considered to be superior to either corn or barley used separately, based on research at Oregon State College. This increased value of corn and barley in combination is reflected in the productive energy coefficient for P_8. Cf. W. G. Brown and G. H. Arscott, "Substitution Value of Barley and Fat for Corn in Broiler Rations," Agr. Exp. Sta. Circ. of Info. 585, Ore. St. Coll., Corvallis, Ore., November, 1957.

$$(2) \qquad 70 \geq 0.02\ P_6 + 0.054\ P_7 + 0.037\ P_8 + 0.072\ P_9 + 0\ P_{10} + 0.058\ P_{11} + 0.074\ P_{12} + 0.022\ P_{13} + 0.007\ P_{14} + 0.025\ P_{15} + 0.0495\ P_{16} + 0.0444\ P_{17} + 0.025\ P_{18} + 0.0495\ P_{19} + 0.0444\ P_{20} + 0.0250\ P_{21}.$$

The symbols P_6 through P_{21} again refer to the same ingredients as in (1). The coefficients for (1) and (2) were taken from F. B. Morrison.[1] Production energy requirements were specified by Equation (3) and were taken from H. W. Titus, when listed.[2] Some values were inferred from values for similar types of ingredients.

$$(3) \qquad 1670.5 \leq 1.145\ P_6 + 0.811\ P_7 + 1.069\ P_8 + 0.7\ P_9 + 2.878\ P_{10} + 0.76\ P_{11} + 0.78\ P_{12} + 0.874\ P_{13} + 1.035\ P_{14} + 0.58\ P_{15} + 0.68\ P_{16} + 0.7004\ P_{17} + 0.6\ P_{18} + 0.69\ P_{19} + 0.7104\ P_{20} + 0.646\ P_{21}.$$

Equation (4) was used to insure that the variable quantity of feed, 1749 pounds, plus the fixed premix, 251 pounds, would total a ton.

$$(4) \qquad 1749 = 1.0\ P_6 + 1.0\ P_7 + \ldots\ldots\ldots + 1.0\ P_{21}.$$

Since the objective of the linear programming analysis is to find a combination of ingredients which minimizes cost subject to the ration specifications, the cost function must also be specified. In Equation (5), T. R. refers to total revenue, but actually represents total cost since each negative coefficient represents the price per pound of that ingredient.

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[1] Feeds and Feeding, 21st Ed., The Morrison Publishing Co., Ithaca, N. Y., 1948.
[2] The Scientific Feeding of Chickens, Rev. of 2d Ed., Danville, Illinois, 1955.

(5)

$$T.R. = -\$0.031 P_6 - 0.0225 P_7 - 0.02675 P_8 - 0.019 P_9 - 0.08 P_{10} - 0.045 P_{11} - 0.039 P_{12} - 0.052 P_{13} - 0.077 P_{14} - 1.0 P_{15} - 1.0 P_{16} - 1.0 P_{17} - 1.0 P_{18} - 1.0 P_{19} - 1.0 P_{20} - 1.0 P_{21}.$$

The artificially high prices for all torula yeast or bacterial concentrate processes prevent these ingredients from entering the solution. Then, after finding a minimum cost ration using the other feeds, it is easy to calculate the highest prices at which torula yeast or bacterial concentrate would enter the solution. The quantities which would be used in the ration are also readily computed.

For the preceding sets of equations, prices, and feed ingredients, the minimum cost ration consisted of 438.2 pounds corn, 278.1 pounds meat and bone scrap, 483.1 pounds soybean meal, 549.6 pounds of the 50-50 corn-barley mixture.[1/] Protein, energy, weight, and fiber requirements are met exactly by the preceding quantity of ingredients. The cost for this variable portion of the ration, 1749 pounds, is \$51.93 or \$59.38 per ton.

This cost of \$59.38 per ton is the very minimum that can be achieved for the prices, ingredients, and requirement assumptions used. The next step in evaluating torula yeast and bacterial cells is to calculate the break-even prices at which activities P_{15} through P_{21} would just enter the solution. For example, for P_{15} (torula yeast), 105 pounds per ton of ration should be used if the price of torula yeast were not more than \$85.97. A slightly lower price of \$83.40 per ton would induce an even greater usage of 257 pounds of torula yeast. In order that the total savings per ton of chick ration from using torula yeast equal \$0.50, the selling price would need to be around \$81 per ton or about \$5 per ton less than the highest price which would bring it into the ration.

1/ Actually, the grain component amounts to 713 pounds corn and 274.8 pounds barley, but the productive energy content of the ration is calculated as first stated.

Essentially the same procedure was followed with bacterial cell concentrate and for the other poultry rations tested. The ration specifications were changed for other poultry rations, but the same coefficients for feed ingredients were used.

PROCEDURE USED FOR EVALUATING TORULA YEAST AND BACTERIAL CONCENTRATE IN DAIRY RATIONS

A model and procedure similar to that followed for the poultry rations was employed to deduce feeding values for the 16% and 18% protein dairy rations listed in Tables 2 and 3. One difference was that the protein requirement, corresponding to Equation (1), was stated in terms of digestible protein rather than crude protein. The digestible protein requirement was set at 262 pounds per ton for the 16% (crude) protein ration and at 292 pounds for the 18% dairy ration.

Since ruminants are able to digest cellulose satisfactorily, the fiber restriction, Equation (2), was dropped out of the model. Energy requirements were set at 75% total digestible nutrients instead of being stated in terms of productive energy as for the poultry rations in Equation (3).

Weight requirement of 2000 pounds of final mix was set up in the same manner as Equation (4). Prices used were the same as for Equation (5). One difference in ingredients was that cottonseed meal was allowed to enter in unlimited quantities in the dairy ration.