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FOREWORD

This paper is one of a series reviewing various forms of traditional agricultural production and related aspects. Preliminary work on this review was carried out within the scope of activities of the Food and Agriculture Program's Task 2 ("Technological Transformations in Agriculture: Resource Limitations and Environmental Consequences"). One of the goals of this task's activities is the review of various alternative technologies available in the world for the production of major crops and animal products.

In this task, the problem of achieving sufficient protein production for animal feed and the human diet is an important one. A review of nontraditional technologies for the production of protein was started after a task force meeting was held at IIASA in September 1980 (see *Proceedings of a Task Force Meeting on New (Non-traditional) Technologies for the Utilization of Agricultural Wastes and By-products, CP-81-18)*. An overview of the possible ways of increasing the output of feed protein was carried out as a part of these activities and this is the subject matter of this paper. The information presented here is by no means complete; further details will be needed. However, the paper's value lies in the fact that it is one more step in the direction of an assessment of possible means of coping with the overall problem of producing sufficient protein.

Research work on the topics presented has been carried out partly at IIASA and partly at the All-Union Research Institute of Information and Technical-Economic Research in Agriculture.

Kirit S. Parikh
Program Leader
Food and Agriculture Program

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SUMMARY

A wide range of protein sources is used in highly developed countries to meet the requirements of farm animals for protein. Traditional feed, such as grain, cake, meal, field forage crops, and pasture and meadow grasses, still remains the basic source of protein. However, due to the world's protein deficiency, nontraditional proteins such as monocelled protein, nonprotein nitrogenous compounds, and the protein concentrate Vepex are widely used.

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INTRODUCTION

Research and agricultural practices in the Soviet Union and in other countries suggest that the quantity and quality of animal products depend on how the feeding rations are balanced, especially with regard to protein. Current requirements of feed protein are estimated at 432×10^6 tonnes. This figure will reach 524×10^6 tonnes by 1990 and 640×10^6 tonnes by the year 2000 (Kulikov and Slesarev 1979).

Highly developed animal husbandry in the majority of countries is considerably deficient in feed protein. Therefore, various traditional sources of protein are widely used while investigations are made into ways of increasing protein production.

The most effective methods of solving the protein problem are to

- provide a steady increase in the production of plant protein by enlarging the area of cultivated land, with an increase in the yields of grain, leguminous, and feed crops;
- intensify and rationalize the use of haylands and pastures;
- improve the technology of production and storage of roughage and succulent feed;
- increase the production of formulated feed;
- rationalize the use of industrial wastes and sea products for animal feeding;

- identify and use new protein sources such as microorganisms; use by-products of the oil-processing and chemical industries, as well as nonprotein nitrogenous compounds, protein concentrates, etc.

Protein of plant origin plays a key role in solving the problem of increasing worldwide production of feed protein. Plant protein comprises over 90% of the total protein in farm animal diets.

1. THE USE OF GRAIN FOR FEED

World feed grain production (corn, barley, oats, sorghum, and rye) in 1978/79 was estimated at 713.6 x 10^6 tonnes, compared with 701.7 x 10^6 tonnes in 1976/77 (FAO 1979). The world feed grain consumption in 1977/78 amounted to 481.7 x 10^6 tonnes, compared with 445.0 x 10^6 tonnes in 1974/75 (Committee on Commodity Problems 1980).

Table 1 presents data on feed grain consumption in the US and a number of Western European countries. These data indicate that feed grain consumption in the US, with year-to-year variations, is rather high, amounting to approximately one quarter of the world total.

Table 1. Consumption of feed grain, 10^6 tonnes.

Country	1973/74	1974/75	1975/76	1976/77	1977/78	1978/79
US	143.3	106.5	117.2	114.6	122.5	138.3
France	17.2	16.8	16.8	16.2	17.4	18.8
Great Britain	13.0	12.7	11.8	12.4	11.9	12.1
FRG	16.6	16.5	16.5	16.2	15.9	16.1
Denmark	5.7	5.1	5.4	4.6	5.3	5.4

SOURCES: US Department of Agriculture 1980 (for the US) and Commission of European Communities 1977-80 (for Western Europe).

Grain consumption in the US, calculated per cattle unit, was 14.8 quintals (1 q = 100 kg) in 1976 and 15.0–15.6 q in 1977/78. In west Europe feed grain is used more economically and with only slight, if any, year-to-year variation, which is due to a lower volume of feed grain production and higher prices for imported grain (the same explanation applies to the lower rates of grain consumption for the production of animal products).

Varieties of grain feed crops with higher protein content and improved amino-acid composition would also be more economical. Intensive breeding research aimed at the development of such varieties of corn, barley, oats, and triticale is being carried out in the USSR and other countries. New barley varieties Prizyv and Novator with 17–19% protein have been developed in the USSR. These varieties are superior to other regionalized varieties in productivity and protein content. A high-protein, early, short-stemmed barley variety Norin-4 has been developed in Japan using hybridization. Barley mutants that are superior to the initial varieties in protein content by 1.5–2.0% have been developed in the GDR, the FRG, Czechoslovakia, and other countries. In the US large-scale breeding research resulted in the development of new oat varieties such as Goodland, Del, and Oty with a protein content of about 20%. In a number of countries research is under way to breed corn of better quality and higher protein content. High-lysine corn hybrids with a yielding capacity close to that of common hybrids have been developed using the Opaque-2 mutant. In the USSR a number of regionalized hybrids have been transformed into high-lysine varieties; these are VIR 25 VL, VIR 42 VL, VIR 329 VL, VIR 156 VL, Kubansky 303 VL, Kubansky 304 VL, etc. (Koloskina 1979a, Koloskina 1979b).

2. THE USE OF HIGH-PROTEIN FEED OF PLANT ORIGIN

Leguminous and oil crops are the main sources of protein for high-protein feedstuff in the world. According to the US Department of Agriculture (USDA), world production of oilseeds increased from 140.5×10^6 tonnes in 1975/76 to 158.9×10^6 tonnes in 1978/79.

Oilseed production is mainly increased by extending the area of land planted to oil crops in the main oil-crop producing countries, although in some countries an increase in output is simply due to greater yields. Given below are selected data regarding the increase of land under principal oil crops in the main oil-crop producing countries.

Table 2. Increase of land planted to principal oil crops, 10^6 ha.

Crop	Country	1972/73–1976/77 (average)	1978/79
Soybean	US	20.7	25.5
	Brazil	5.6	7.9
	Argentina	0.4	1.7
Sunflower	US	0.3	1.2
	Argentina	1.2	1.6
Rape	Canada	1.3	2.8
Flax	Argentina	0.5	0.8

As shown in Table 2, the yield of soybean in the US increased from 18.0 to 19.9 q/ha and in Argentina from 17.2 to 22.4 q/ha during the same period. The yield of rapeseed in Canada increased from 10.0 to 12.4 q/ha and in France from 19.9 to 22.6 q/ha. The yield of flax in Canada increased from 7.8 to 10.9 q/ha. Some increase in the yield of cottonseed is known for the US, India, and Pakistan.

Soybean is the most widely grown oil crop. The main soybean producers are the US, Brazil, China, and Argentina. In 1978/79 the world soybean production amounted to 80.1×10^6 tonnes (see Table 3), of which 50.1×10^6 tonnes were produced in the US, 11.0×10^6 tonnes in Brazil, 10.5×10^6 tonnes in China, and 3.8×10^6 tonnes in Argentina.

Table 3. The world production of oilseed, 10^6 tonnes.

Crop	1975/76	1976/77	1977/78	1978/79
Soybean	68.0	61.3	74.3	80.1
Cotton	22.5	23.2	25.3	24.3
Peanut	18.8	16.9	17.0	18.3
Sunflower	9.9	10.0	12.7	12.3
Rape	8.8	7.5	8.0	11.2
Sesame	1.8	1.7	1.8	1.7
Safflower	1.0	0.7	0.8	1.0
Flax	2.5	2.3	3.1	2.8
Castor-oil plant	0.7	0.8	1.0	1.0
Copra	5.3	4.8	4.9	4.7
Palm	1.0	1.2	1.2	1.3
TOTAL	140.5	130.5	150.3	158.9

Interest in soybean cultivation is motivated by the growing demand for plant oil and high-protein feed. A further contributing factor is the biological ability of the soybean plant to use up to 200 kg of nitrogen from the atmosphere per hectare of crop area. Therefore, the total area planted to soybean in the world extended from an average of 39.1×10^6 ha in 1972/73–1976/77 to 48.8×10^6 ha in 1978/79, and production increased from 60.2×10^6 tonnes to 80.1×10^6 tonnes.

The US is now self-sufficient in high-protein feedstuff, exporting large quantities of soybean and soybean products to Western Europe and Japan. Brazil is the second largest soybean producer and exporter. Soybean production in Brazil has increased considerably since 1969, reaching 9.2×10^6 tonnes in 1977.

Among other oil crops, sunflower and rape have gained more recognition during recent years. The world sunflower output in 1977/78 amounted to 12.7×10^6 tonnes

The leading sunflower producers are the USSR, Argentina, the US, and Rumania. In the USSR the production of sunflower seed amounted to 5.33×10^6 tonnes in 1978 and 5.37×10^6 tonnes in 1979.

An increase in sunflower yielding capacity with the enlarging of cultivated areas contributed to the increase in world sunflower seed production. (The world's cultivated area planted to sunflower increased from an average of 10.5×10^6 ha in 1972/73–1976/77 to 12.2×10^6 ha in 1978/79.) During the same period the yield of sunflower seed increased from 7.6 to 8.7 q/ha in Argentina and from 13.8 to 15.5 q/ha in the US. New varieties with higher oil content and greater resistance to disease, such as hybrid varieties Cargill 204 and Hybrid 894, contributed to the extension of crop area and the increased yield of sunflower seed in the US. In 1977/78 new short-stemmed varieties of sunflower with an oil content of 45–50% were used. The above varieties are well suited to mechanized harvesting and grow fairly well in many regions of the US. In 1977, 95% of the area used for sunflower cultivation was seeded with hybrids, compared with only

15% in 1974.

The major rape growing countries are India, Canada, and China. Western Europe produces considerably lower amounts of rape. In recent years the crop area and rape production in Canada increased considerably: the area from an average 1.3×10^6 ha in 1972/73–1976/77 to 2.8×10^6 ha in 1978/79; production from 1.3 to 3.5×10^6 tonnes; and crop yield from 10.0 to 12.4 q/ha. Some increase in crop area and rape production is also observed in India and China.

During the same period world production of rape increased from 7.9 to 11.2×10^6 tonnes, with an enlargement of crop area from 9.3 to 11.4×10^6 ha and an increase in yield from 8.8 to 9.8 q/ha.

Considerable work to improve rape varieties has been carried out in Canada. In the 1960s breeding was mostly aimed at a higher yield and oil content, then in the late seventies at a better chemical composition of oil and meal. In 1973 rape varieties with no erucic acid in the seed (such as Oro, Zephir, and Span) occupied over 85% of the land under rape cultivation (USDA 1979). In Canada the new spring rape varieties Midas and Torch, containing no erucic acid, were developed. Subsequently, other new spring rape varieties low in erucic acid and glucosinolates and high in meal protein were developed, such as Tower in 1974, and Regent and Ultex in 1977/78. In 1977 the winter rape variety Candle with a higher content of protein and oil (by 2–3%) and a lower glucosinolate content was developed by interspecific hybridization involving two species of rape and mustard.

In the EEC countries, rape breeding is directed toward higher crop yielding capacity and greater resistance to disease, early maturity, elimination of erucic acid and glucosinolates, and a lower content of linolenic acid.

3. INCREASING THE YIELD OF FIELD FORAGE

Increasing protein output in forage production is achieved mainly by intensification, application of optimum amounts of fertilizers, and by the development and introduction of more productive feed crop varieties.

Fertilizer application is one of the main methods of producing more protein and dry matter. Research data indicate that the application of balanced mineral fertilizers in the nonchernozem zones of the USSR results in a 50–70% higher yield of protein in sunflower green mass/ha and a 1.5–2.0 increase in the protein yield of green mass/ha of corn (1976).

Experiments with fertilizer application to green crops carried out at the Kurganskaya Experimental Station, USSR, indicated that an increase in the nitrogen application rate from 40 to 240 kg/ha with phosphorus and potassium dosages being constant ($P_{80}K_{80}$) resulted in a yield of digestible protein in sunflower seeds 1.3–2.5 times higher than the yield in the check plot with no additional nitrogen applied (the yield in the check plot was 2.7 q/ha); the output of feed units increased by 21–36%. The yield of digestible protein from corn in the same experiment was 1.7–3.5 times higher than that in the check plot (1.6 q/ha) with a 48–90% increase in the output of the feed units (Smurygin 1974).

In the experiments carried out at the Perm Agricultural Institute the application of a wholly mineral fertilizer (nitrogen, phosphorus, and potassium) resulted in an increase in protein in the total yield of roots and tops of fodder and sugar beet of 45–48%; an 80% increase in protein yield was observed for turnips and swedes.

High rates of nitrogen application to winter rye grown for green feed augmented considerably the protein content in the green mass. When only PK was applied (as a background), the protein content in the green mass was 12.7%; the treatment PK + N_{34} resulted in a protein content of 16.4%; PK + N_{68} gave 19.5%, and PK + N_{102}, 21.4%. The application of N_{102} (with PK as a background) increased the yield of protein from 244 to 554 kg/ha (Prokoshev and Korlyakov 1979).

It has been shown that the crude protein content in corn grown for silage can be raised by aerial application of a urea solution 2–3 weeks before harvesting (at a milky stage of grain maturity). The nitrogen application rates varied from 30 to 60 kg/ha depending on corn yielding capacity. According to the data obtained at the All-Union Research Institute of Civil Agricultural Aviation, USSR, a 30% urea solution proved to be most effective. The aerial application of this solution resulted in an additional 137 kg/ha of crude protein (average for the 6-year period); similar tests at the All-Union Research Institute of Maize showed even greater crude protein yield increments (180–190 kg/ha). The profitability of the above treatment was estimated at 3 rubles of net income per ruble of input (Pavlov et al. 1975).

Experiments carried out in Poland, Rumania, and Czechoslovakia demonstrated that nitrogen fertilizer application to such crops as Italian ryegrass and corn resulted in an additional 2.0–4.5 q/ha of crude protein as well as an increase in crop yield (Nelken and Szczygielski 1976, Balan et al. 1976).

The Hungarian Agricultural Institute studied growing corn for silage. The yields of dry matter and digestible protein in the check plot without fertilizer were 112.8 and 3.8 q/ha, respectively. The application of a complex mineral fertilizer at a rate of 125 kg/ha of active ingredients (2:1:0.5 formulation) resulted in 154.2 q/ha of dry matter and 6.6 q/ha of digestible protein. At a rate of 375 kg/ha a.i., the figures were 188.3 q/ha and 8.7 q/ha, respectively.

In the northern part of the GDR an increase in the nitrogen application rate from 75 to 150 kg/ha raised the crude protein content in rye grown for feed from 16% to 19% (Simon and Pfannkuchen 1974).

Experiments at farms in Denmark demonstrated that high rates of nitrogen application to fodder beet and perennial grasses considerably increased the yield of feed units and digestible protein. Nitrogen applied at an average rate of 200 kg/ha of fodder beet resulted in a yield of 8766 feed units/ha; and at a rate of 360 kg/ha, in 9040 feed units. Digestible protein content in one feed unit amounted to 67 g and 90 g, respectively. Nitrogen applied at a rate of 150 kg/ha to perennial grasses resulted in a yield of 5900 feed units/ha, and at a rate of 450 kg/ha in 7350 feed units. One feed unit contained respectively 150 g and 186 g of digestible protein (Pedersen 1975).

Researchers in the state of Nebraska in the US have found that sulphur application substantially raises the yield of protein in alfalfa (Sulphur Institute 1977).

Fertilizer application is especially effective on irrigated crops. According to research data from the GDR using average figures for 10 years, irrigation combined with fertilizer application (360 kg of nitrogen per hectare of grass; no fertilizer for legumes) resulted in the following yields of dry matter and crude protein: for Italian ryegrass, 165 q/ha of dry matter (a 21% increment over dry matter yields without irrigation) and 24 q/ha of crude protein; for orchard grass, 164 q/ha (a 36% increment) and 26 q/ha; for meadow fescue, 145 q/ha (a 21% increment) and 23 q/ha; for annual ryegrass, 142 q/ha (a 22% increment) and 20 q/ha; for alfalfa, 143 q/ha (a 15% increment) and 33 q/ha; and for red clover, 134 q/ha of dry matter (a 24% increment) and 24 q/ha of crude protein. Besides that, the application of nitrogen fertilizer combined with irrigation resulted in a further increment in the crop yield. For example, the increment in the crop yields of gramineous species amounts to 8–10% (12–18 q/ha of dry matter) (Schalitz et al. 1979).

Commercial tests performed in the forest–steppe zone of the Novosibirsk region, USSR, demonstrated the high effectiveness of corn cultivation under irrigation. The yield of green mass increased by 222 q/ha (431 q/ha with irrigation against 209 q/ha without). Averaged over two years every irrigated hectare yielded 2.1 times more feed units (64.7 q/ha against 31.4) and 2.3 times higher net profit (375.9 rubles against 163.3). Irrigation of perennial grasses increased the yield of green mass from 59.4 to 247.4 q/ha (4.2 times), the yield of digestible protein from 160.4 to 791.7 q/ha, the yield of feed units from 10.7 to 52.0 q/ha, and the net profit from 75.8 to 383.1 rubles. The additional net profit repays the necessary capital investment in land reclamation within 4.6 years. The cost price of one feed unit of irrigated corn was 3.6 kopecks, which is 16.6% lower than the cost price of dry-land corn (Kirillov 1979).

An important method of increasing feed production is selecting the most productive and economical crops according to soil and climatic conditions. In recent years a tendency has been observed toward enlarging the areas planted to corn grown for silage, which is considered a highly productive feed crop. In the FRG, for example, silage corn covered 0.19×10^6 ha in 1970, 0.4 in 1974, and 0.6 in 1978. In Poland the average area of silage corn was 0.3×10^6 ha in 1971–75, and almost 0.7×10^6 ha in 1978 (COMECON 1976, 1979).

In arid and semi-arid regions of the US the introduction of sorghum augmented the grain production substantially. In these regions sorghum and Sudan grass grown for green forage and silage are indispensable crops (Posmytny 1970).

In regions of intensive animal husbandry in Bulgaria the most important crops are corn and alfalfa; the extension of areas planted to the above crops as well as their cultivation under irrigation are therefore envisaged (Dimitrov 1972). In Poland, the extension of areas under the following crops is considered promising: silage corn yielding over 600 q/ha of green mass, sugar beet and semi-sugar beet, alfalfa and clover (cultivated as pure crops and as mixed stands), kale, and bird's-foot

(Swietlikowska 1972).

In Canada, Great Britain, France, and some other countries work is under way to develop varieties of annual large-seeded legumes, such as white and yellow lupines and fodder beans, that would have a high yielding capacity, early maturity, and high resistance to disease (Swietlikowska 1972, Picard 1975, Lees 1976).

Lupine is one of the foremost high-protein crops. To increase protein production in the USSR it is expedient to use the light soils of the forest zone for lupine, loams for peas and fodder beans, and to expand the area under field pea in the nothern parts of the forest zone. Areas under soybean are to be extended in the Far East and in the irrigated lands of the northern Caucasus, southern Ukraine, and Moldavia.

Perennial grasses are one of the main sources of protein and vitamins; therefore in the clover-producing areas of the USSR it is considered expedient to extend the sowing of red clover. The extension of alfalfa sowing is important not only in traditional alfalfa areas, but also in the forest zone on calcareous and limed soils (Smurygin 1974).

In Hungary alfalfa satisfies 25–27% of the requirements for feed protein. The most modern farms have hay yields of 80–100 q/ha or 16–20 q/ha of protein. In the US alfalfa for hay production grown on irrigated land as well as in humid areas represents the main source of high-protein feed not requiring mineral or nitrogen additives. In the state of Michigan, proper selection of varieties and annual application of P_2O_5 (110 kg/ha) and K_2O (330 kg/ha) on neutral soils result in 3–5 cuts yielding at least 18 q/ha of hay (Tesar 1978/79).

Annual crops such as corn, sorghum, rye, oats, ryegrass, and sunflower with legumes (vetch, soybean, peas, lupine) are of great importance in augmenting the protein content in the green mass of feed crops and in hay and silage. Such crops are extensively grown in the FRG, the GDR, Bulgaria, and Poland.

Mixed sowings of corn and sunflower with pea and vetch in forest and forest–steppe zones, as well as corn with soybean in Moldavia, the Ukraine, the northern Caucasus, the Far East, Central Asia, and in other regions, produce 45–65% more protein per hectare compared with single crop sowings. In the nonchernozem zone of the USSR pulses are extensively sown with cereals (barley, oats, rye, etc.), especially vetch with oats. As a rule the vetch–oats combination is more productive than single crop sowings. Experimental growing of vetch, oats, and ryegrass at the All-Union Research Institute of Feedstuffs, USSR, has been even more impressive – a hay yield of 77.3 q/ha with a protein output of 13.0 q/ha; the vetch–oats combination resulted in 35.3 q/ha and 6.6 q/ha, respectively. Good results were obtained in sandy soil when bird's-foot was added to the three-crop mixture. A field pea–oats mixture grown in light soil in the northern part of the nonchernozem Central region proved to be very effective.

Mixed sowings of sunflower with pulses contribute to increased yields from feed units and make feedstuffs more balanced in digestible protein compared with sunflower grown as a single crop.

In tests carried out in Poland corn and soybean were sown in alternate rows; this resulted in an increased protein yield of 4.3 q/ha (18.9 q/ha against 14.6 q/ha for corn grown alone) (Tabin 1975).

In Yugoslavia experimental plantings of winter rye and barley mixed with hairy vetch yielded 7.6–8.5 q/ha of protein, while rye and barley grown individually yielded 6.4 q/ha and 4.5 q/ha, respectively (Pejic 1976).

Mixed sowings of pea with cereals such as barley, oats, and wheat are recommended in Canada. At the Charlottetown Experimental Station pea mixed with barley yielded 4.8–8.3 q/ha of protein; pea with oats gave 4.2–8.3; and pea with wheat, 4.8–8.1, which is considerably more protein than from individually grown cereals (Johnston and Sanderson 1978).

Catch cropping provides a further increase in the production of feedstuff and protein from plowed land. Experience gained in research institutions and on state and collective farms confirms the possibility of using catch cropping in the Central Asian and Transcaucasian republics, the Ukraine, Byelorussia, Moldavia, southern Kazakhstan, and in the following economic regions of the Russian Federation: the North-Western, nonchernozem Central, North Caucasus, Volga, and Urals.

In Moldavia, irrigated cropping permits two or even three crops of forage per year. Experiments made at the Kishinev Agricultural Institute have shown that a maximum yield of 238.4 q/ha of feed units and 25.5 q/ha of digestible protein resulted from three crops per year (1974/75 data) – winter rye, corn, and a vetch–oats mixture – with the yield of green mass being 452.5, 570.0, and 344.5 q/ha, respectively (Snegovoy and Kuzmenko 1976).

Data obtained in the FRG indicated that stubble crops bring about 2.4–4.0 q/ha of additional protein. Furthermore, catch cropping prolongs the feeding of cattle with fresh green forage by 50 days: in early spring by winter sowings of rape and winter cress, and in late fall by stubble crops of kale, winter rape, oil raddish, etc. (Schaffer and Knuepfer 1975).

In Bulgaria catch cropping is practiced only under irrigation due to insufficient rainfall in the second half of summer. At the Institute of Animal Husbandry (Stara Zagora) experiments have been made showing that sunflower, winter cress, pea, and oats may be grown as stubble crops, individually or in mixtures, for feed purposes. Among single crop sowings the highest yields were obtained from sunflower (416.5 q/ha) and oats (194.1 q/ha); among mixed sowings, from sunflower with oats and pea (327.7 q/ha) and winter cress with oats and pea (216.9 q/ha). The protein content in the green mass of stubble crops increased by 3% at the second sowing and by 8% at the third sowing (1972).

Catch cropping as a cheap additional source of feed and protein is widely practiced in the FRG. Catch crops grown after cereals yield 1600–2000 kg of starch units and 500–600 kg of digestible protein per hectare. Reportedly, the cost price of 1 kg of starch units from catch crops is 0.25–0.34 deutsche marks cheaper than purchased barley. In particular, Cruciferae spp. such as rape, winter cress, mustard, and oil raddish, which have rather high yielding capacities and are well suited to late sowing, are widely grown in the FRG by catch cropping (Marquering

1973).

One way of increasing protein output in forage production is to develop intensive-type varieties of feed crops with high yielding capacities, resistance to disease, and protein content. In recent years a number of such varieties has been developed in many countries. An example is the red clover variety Tetraploid VIK developed at the All-Union Institute of Feedstuffs, USSR. This variety yielded 121.9 q/ha of dry matter and 18.3 q/ha of protein (average data for an 8-year trial period). This exceeds considerably the yield potential of the standard diploid variety Moskovsky 1 (Smurygin 1974).

In the GDR a new tetraploid red clover variety, Perenta, has been developed that is 3–4% superior to diploid varieties in protein content. The tetraploid variety Matry developed in the GDR has a high yielding capacity and protein content. Irrigation increases considerably its yield potential: the green mass yield with irrigation is 927 q/ha and 649 q/ha without; the yield of dry matter is 132.1 and 100.4 q/ha, respectively; the yield of crude protein, 25.8 and 19.0 q/ha respectively (Witt 1977).

The red clover tetraploid Tatra developed in Czechoslovakia is a high-yielding variety which allows three cuts if irrigated (Polák 1974).

The new alfalfa variety Verko, developed jointly by plant breeders from the GDR and Hungary, is characterized by a high yielding capacity, high rates of regrowth in the spring and after cutting, and high resistance to bacterial wilt. The dry matter content in the green mass amounts to 19.5%; the crude protein content as calculated for the dry basis to 19.9–20.2% (Witt 1979).

The new field pea variety Kormovaya-50 developed in the USSR is less sensitive to variations in temperature and is characterized by high rates of increase in green mass weight. In the Altai Territory of the USSR the yield of green mass reached 273 q/ha and the yield of hay, 90 q/ha. The protein content in green mass amounts to 19–21%, in grain to 22–26% (Kandaurov 1978).

The new kale variety Mazek developed in the GDR can be grown as a basic crop, a second crop, and a stubble crop. The crude protein content in the dry matter amounts to 17.3% for the first crop and 23.0% for the stubble crop. When sown in late June this variety yielded 358 q/ha of green mass (Nasinec and Klement 1977).

The yield of green mass from the kale variety Inca developed in Czechoslovakia amounted to 1300 q/ha for the first crop; the yield of dry matter was 130 q/ha; and the yield of digestible nitrogenous substances, 28 q/ha. The good quality of stalks (i.e., low lignin content in the upper part) makes for better palatability (Magyarosi 1978).

The new fodder rape variety Samo developed in Sweden has a lower content of glucosinolates, a high yielding capacity, and a high crude protein content (422–459.9 q/ha of green mass, 8.6–9.2 q/ha of crude protein) (Smurygin 1974).

4. EFFECTIVE METHODS OF MAXIMIZING FEED PRODUCTION

In order to raise the protein yield from feed crops it is extremely important to specify the optimal harvest time for a specific crop. Soviet research data suggest that proper timing for forage may result in a 20–25% greater gross protein yield in the country (Smurygin 1974). Experiments at Michigan State University demonstrated that three cuts of the alfalfa variety Vernal at the beginning of the flowering stage yielded more dry matter (119.7 q/ha), crude protein (24.7 q/ha), and digestible nutrients than three cuts at more advanced stages of growth (McGuffey and Hillman 1976).

Perfecting the technology of procurement and storage of succulents (silage, haylage) and roughages (hay), which are the basic sources of feed in countries with highly developed animal husbandry, is considered to be of great importance.

In the US annual production of bulk feed amounts to over 100×10^6 tonnes of silage and over 120×10^6 tonnes of hay. The annual amounts in million tonnes for France are 55.0 for silage and 55.7 for hay; for the FRG, 30.0 for silage and 36.6 for hay; and for Great Britain, 17.0 for silage and 9.3 for hay.

To reduce the loss of nutrients, especially of protein during feed procurement and storage, technological practices such as optimal harvest time for silage and hay, wilting, and the use of chemical conditioners are much stressed in the US, France, Netherlands, and Great Britain. Given below are harvest times for the principal silage crops with yields of dry matter and digestible protein obtained at harvesting (Baylor 1976).

Table 4. Harvest times for the principal silage crops and yields of dry matter and digestible protein obtained at harvesting.

Crop	Harvest time (stage of crop development)	Yield, tonnes/ha	
		Dry matter	Digestible protein
Corn	Wax	13.5	0.68
Sorghum	Milky/wax	13.5	0.68
Sudan grass	Beginning to flower	7.9	0.48
Alfalfa	Budding	11.2	1.70
Pulse/grain mixtures	Leguminous plants beginning to flower	10.0	1.02

According to data obtained at INRA, France, silage alfalfa harvested at the bud stage contains 0.67 feed units/kg of dry matter compared with 0.57 units/kg of dry matter of silage alfalfa harvested at the flowering stage. The digestible dry matter content was 165 g/kg against 145 g/kg, respectively (Andrieu 1976, Vincent 1978).

According to data from the Research Institute of Animal Husbandry, Hungary, alfalfa silage harvested at the earlier stages of growth has the highest content of nutrients and protein (Table 5) (Szentmihálytt et al. 1978).

Table 5. Content of nutrients in alfalfa for silage.

Stage of development	Dry matter content	Content of nutrients/kg dry matter		
		Starch units	Digestible protein	Crude cellulose
Leafing	145	586	221	207
Beginning to bud	185	551	189	243
Budding	210	514	171	262
Flowering	230	439	143	296
Post-flowering	250	359	128	328
Seed formation	280	296	103	371

In Great Britain rye and barley are used to make silage, as well as corn. According to the data the beginning of the flowering stage is the optimal harvest time for silage rye. Rye harvested at this stage yields 8.5×10^6 tonnes/ha of dry matter; crude protein amounts to 9.7%; digestibility to 66% (Haigh 1977).

The optimal dates for cutting grasses for silage are of importance. For instance, in the US it is recommended to start cutting alfalfa for hay (the annual output of hay is 70×10^6 tonnes) no later than the flowering stage (at budding stage) so that the digestibility of the nutrients is not less than 55% and the protein content not less than 21%. According to data presented by the specialists in Illinois the intake of such hay was 2.2 kg/100 kg of liveweight versus 1.6 kg of hay from later cuts.

In Finland grasses for top-quality hay are used intensively (2–3 cuts at earlier stages of growth). The production of dry matter amounts to 60–80 q/ha, the production of crude protein being 15–20 q/ha.

Field and chemical wilting of fresh-cut grass also contributes to a higher dry matter and protein content in feed. This practice is widely spread in Belgium, the Netherlands, Great Britain, the FRG, France, New Zealand, Canada, and other countries.

According to the research data from Belgium (Leuven), field wilting of alfalfa for 31 hours and of ryegrass for 52 hours results in an increase in dry matter content in ensiled material from 20.83% to 31.78% and from 17.43% to 27.84%, respectively. Wilting the same crops by chemical conditioners also resulted in a higher dry matter content, though to a lesser extent; namely, 23.32% in the ensiled alfalfa and 20.94% in the ensiled ryegrass. Formic and acetic acids were used as conditioners and were added at dosages of 0.43% and 0.40% by weight, respectively (Arnould et al. 1978a).

In Great Britain the Service of Agricultural Development recommends field wilting of grasses harvested for silage for 36–48 hours to obtain a moisture content of 70–75% in good weather and 80% in bad weather; chemical conditioners are also recommended. According to data presented by the Institute of Range and Pastures in Harley, the addition of formic acid (3.4 l/tonne of ensiled material) results in an increase in dry matter content from 19.5% to 27.7% (Haigh 1978).

In many Western European countries chemical conditioners such as organic acids, formaldehyde, and anhydrous ammonia are widely used to improve the quality of feed and to reduce losses during silage fermentation. The most widely used conditioners are organic acids, especially formic acid. It has been found in France that adding 6 liters of formic acid and silozan to 1 tonne of ensiled alfalfa yields feed (20.75% dry matter) containing 0.7 feed units/kg dry matter and a protein content of 214 g. Formaldehyde treatment of silage slows down the fermentation process, suppresses putrefactive microflora, and considerably limits the decomposition of nitrogenous substances (Bertrand and Guemere 1977).

According to data presented by Belgian researchers, 3 kg of formaldehyde added to 1 tonne of ensiled grasses considerably enhances the conservation of protein and lowers the ammonia nitrogen content by 50–75% compared with untreated silage. Formaldehyde applied at the rate of 2 kg/tonne of silage ensures an 80% preservation of protein in alfalfa silage compared with 40% in untreated silage; it provides a 44–68% preservation of protein in soybean (Arnould et al. 1978b). Anhydrous ammonia is used in the US, Canada, and France as a conditioner and to raise the content of nitrogenous substances in bulk feed. Studies indicate that anhydrous ammonia added at ensiling (especially to corn) increases buffering and prevents secondary fermentation while raising the protein content. Thus, experiments carried out in the US and in Canada demonstrated that anhydrous ammonia added to ensiled corn with 35% of dry matter at rates of 3.0 and 3.5 kg/tonne raised the protein content from 7.9% to 12.4% and from 10.0% to 14.0%, respectively.

In the US the Pro-Sil preparation (which is a suspension of ammonia, molasses, and mineral compounds) is used to raise the protein content in corn silage. Pro-Sil added at the rate of 22.7 kg/tonne raises the protein content from 8.4% to 13.8%. Anhydrous ammonia is also used to treat bales of grass hay as well as legume and grass–legume hay with a 33% moisture content to reduce the loss of dry matter and to increase the crude protein content. Thus, the dry matter loss in the ammonia-treated hay (at a rate of 1% by weight) was 10.9% against 19.1% in the untreated hay; crude protein content in the ammonia-treated grass hay was 15.1% against 11.3% in the untreated; for grass–legume hay, the figures were 14.6% and 12.4%, respectively (Loir 1977, Widmer 1978, Saint-Ellier 1979).

5. THE PRODUCTION OF FORMULATED FEEDSTUFF AND FEED ADDITIVES

Formulated feedstuff and feed additives represent most important sources providing balanced rations of protein, mineral nutrients, and vitamins for farm animals and poultry.

Formulated feedstuff not only provides for an economical and efficient use of feedstuff, including protein feed, but also raises milk and meat productivity. In some countries the production of formulated feed has reached a very high level. For instance, in the Netherlands and Japan nearly all concentrates are fed as formulated feed. In the US the 1978 production of primary formulated feed increased to 70.8×10^6 tonnes; together, the production of primary and secondary formulated feed increased to 98.9×10^6 tonnes – this amounted to 70% of all concentrates used (1979).

The production of formulated feed in the EEC countries has increased substantially in recent years. Table 6 presents data on the use of grain and meal as components of formulated feed in the EEC countries. As can be seen from the data, the percentage of grain in formulated feed decreases, due to greater use of meal, cassava, dried pressed crop molasses, flour-milling by-products, grass meal etc., parallel with the increase in the formulated feed output (Esselmann, 1979a, 1979b).

Table 6. Production and composition of formulated feed in the EEC countries.

	Production, 10^6 tonnes		Proportion of grain, %		Proportion of oil-seed meal, %	
Country	1977	1978	1977	1978	1977	1978
FRG	14.0	14.8	31.8	30.3	31.7	33.0
France	12.5	13.3	49.1	44.0	18.9	18.8
Netherland	12.3	12.7	19.3	19.4	19.2	18.5
Great Britain	10.8	10.9	57.1	50.9	11.6	12.6
Italy	7.8	8.8	61.3	59.2	14.8	15.6
Belgium, Luxembourg	4.9	5.0	36.5	37.9	22.1	24.9
Denmark	3.7	4.2	32.5	29.6	40.7	47.5
Irish Republic	1.4	1.6	74.4	66.6	15.4	19.2
TOTAL	67.4	71.4	41.5	38.9	21.3	22.5

Relative amounts of formulated feed in the diets of all farm animals increase parallel with the increase in formula feed output. From 1970–77 the annual production of formulated feed per cow in the FRG increased from 4.2 to 8.1 q; in France, from 1.1 to 2.7 q; in Italy, from 3.1 to 7.0 q; and in the Netherlands, from 11.0 to 19.1 q. This naturally resulted in a greater milk yield per cow: in the FRG, from 3800 to 4180 kg; in France, from 2841 to 3297 kg; in Italy, from 2842 to 3245 kg; and in the Netherlands, from 4340 to 4825 kg (Esselmann, 1979b).

The value of formulated feed depends to a considerable degree on the content of protein ingredients; namely, cake and oilseed meal. USDA estimates the world output of cake, oilseed meal, and fish meal (calculated in 44% protein soybean meal equivalents) to reach 81.9×10^6 tonnes in 1978/79.

Table 7 presents USDA data on the output and consumption of cake, meal, and fish meal in developed countries with market economies and in developing countries (1978).

Table 7. Production and consumption of cake, meal, and fish meal (calculated in 44% protein soybean meal equivalents), 10^6 tonnes.

	1977		1978[1]		1979[2]	
Country	Out-put	Consump-tion	Out-put	Consump-tion	Out-put	Consump-tion
Developed countries						
Australia and New Zealand	0.2	0.3	0.2	0.3	0.3	0.4
EEC countries	0.9	16.2	1.1	17.9	1.1	19.0
Other Western European countries	1.1	4.2	1.2	4.9	1.2	5.3
Canada	0.7	0.8	1.3	1.5	1.8	1.7
US	28.5	14.1	38.0	15.0	33.8	17.0
Republic of South Africa	0.7	0.7	0.7	0.7	0.7	0.7
Japan	1.2	5.2	1.3	6.0	1.3	6.4
Developing countries						
Argentina	2.0	0.4	3.0	0.4	3.5	0.5
Brazil	9.5	1.8	7.8	1.4	10.2	1.8
Other South American countries	1.2	0.5	1.3	0.6	1.3	0.6
North and Central Africa	2.5	1.5	2.6	1.7	2.6	1.7
Asia	6.0	5.1	6.3	5.5	6.5	5.7
WORLD	66.5	69.7	78.8	77.6	83.7	83.8

[1]Preliminary data.
[2]Estimated data.
NOTE: Cake and meal are produced from local oil crops (soybean, peanut, cotton, rape, sunflower, flax, copra, palm, and sesame).

The data in Table 7 show that the level of consumption of high-protein feed keeps rising in all the countries, but only the US, Brazil, and Asia are self-sufficient. The US is a major exporter of high-protein feed – internal consumption amounts to only 50% of the cake and meal produced in the country.

Fish meal is a major component of formulated feed for nonruminants and an important source of digestible protein, vitamins, mineral nutrients, and nonspecific growth factors. Fish meal is superior to other high-protein feedstuffs in the biologoical value of its protein, which contains such essential amino acids as methionin, lysin, cystine, and triptophane. This is why fish meal is especially effective in starter rations for pigs and poultry. The US feed industry regulates the inclusion of 1.5% fish meal in grower rations and 1.1% in the rations for pedigree sows. However, the world production of fish meal is declining due to high costs and the exhaustion of fish resources. In 1974 the world fish meal production was 4.57×10^6 tonnes compared with 3.55×10^6 tonnes in 1978. During this period a considerable decline in fish meal production was observed in the producing countries: in Peru, from 0.88 to 0.44×10^6 tonnes; in Japan, from 0.77 to 0.64×10^6 tonnes; in South Africa, from 0.26 to 0.16×10^6 tonnes.

Meat-and-bone meal and meat meal are just as valuable as protein feed for pigs and poultry; their production keeps increasing in many countries. From 1974 to 1978 their consumption as animal feed increased in the US from 1.79 to 2.15×10^6 tonnes, in the FRG from 0.09 to 0.18×10^6 tonnes, and in France from 0.19×10^6 tonnes in 1973 to 0.21×10^6 tonnes in 1977. In 1977 the consumption of meat-and-bone and meat meal was 0.24×10^6 tonnes; and in the Netherlands, 0.14×10^6 tonnes.

Meat-and-bone meal is included in formulated feed and concentrates in the following proportions: 13% for suckling pigs and weanlings, replacement gilts (4–8 months old), sows in the second period of pregnancy, and milking sows; up to 8% for sows in the first period of pregnancy and feeder hogs for meat production; up to 10% for feeder hogs for bacon production; up to 8% for calves 1–6 months old; up to 7% for calves 6–12 months old; and up to 7% for mature poultry.

Table 8 presents comparative data on the use of grain and high-protein feed in the livestock industry in EEC countries and the US. These data show that from 1975 to 1978 the consumption of protein feed per 100 kg of grain in EEC countries was 32.6–38.8 kg (including 24.4–30.5 kg of meal and 3.0 kg of feed of animal origin); and in the US, 26.0–27.6 kg (of which 12.0–13.7 kg of meal and 2.0 kg of feed of animal origin were used).

6. NONTRADITIONAL SOURCES OF PROTEIN FOR FEEDING FARM ANIMALS

In addition to traditional sources of protein, there are some nontraditional sources such as monocelled micro-organisms (algae, yeast, fungi, and bacteria) that are rapidly gaining ground. This is due to the very rapid growth and production of these organisms and the possibility of their production from cheap raw material.

In 1975 the world production of protein from monocelled organisms (feed yeast) grown on traditional carbohydrate substrate amounted to 1 million tonnes; by 1980 the world production of feed yeast is forecasted to reach the 2 million tonne level. The major producers of yeast are the USSR, US, France, and the FRG. Currently the annual production of feed yeast in the US, France, and the FRG amounts to 0.2, 0.16, and 0.14×10^6

Table 8. The use of grain and high-protein feed in the livestock industry in EEC countries and the US, 10^6 tonnes.

Grain and high-protein feed	EEC countries 1975/76	EEC countries 1976/77	EEC countries 1977/78	US 1976	US 1977	US 1978	US 1979
Grain	67.7	67.0	67.6	119.4	122.5	138.0	141.3
Meal	16.5	17.7	20.6	14.4	16.8	18.4	19.6
Incl. soybean meal	10.4	10.8	13.8	12.7	14.7	15.8	17.3
Feed of animal origin	2.1	2.2	2.0	2.7	2.7	2.8	2.1
Incl. fish meal, meat-and-bone meal	2.1	2.2	2.0	2.3	2.4	2.5	–
Dehydrated feed (alfalfa etc.)	1.7	1.6	1.7	1.1	1.3	1.4	1.4
Dried fat-free milk and other feed	1.2	1.5	1.4	0.4	0.3	0.3	–
Other protein feed	0.6	0.7	0.5	12.4	12.7	13.0	14.8
TOTAL HIGH-PROTEIN FEED	22.1	23.7	26.2	31.0	33.8	35.9	37.9
Consumption in kg/100 kg grain							
High-protein feed	32.6	35.4	38.8	26.0	27.6	26.0	26.8
Incl. meal	24.4	26.4	30.5	12.0	13.7	13.3	13.9
Incl. feed of animal origin	3.1	3.3	3.0	2.3	2.2	2.0	1.5

tonnes, respectively.

In addition there is a tendency in some countries (among them the US, Great Britain, France, and the FRG) to use oil products, such as gas oil, N-paraffins, and alkanes as raw materials for the production of monocelled protein. At the same time research is under way to produce bacterial protein from gas (on methanol).

The biomass of monocelled organisms is rich in protein. The protein content in algae, yeast, and bacteria varies from 40% to 80% (as calculated on the dry basis). Furthermore, such organisms have a high concentration of lysine which renders the biomass equal in feeding value to good quality fish meal (the content of lysine in algae is somewhat lower). However, the above products are low in the sulphur-bearing amino acids methionine and cystine, which necessitates the incorporation of other proteins in animal diets. Monocelled protein is also rich in the B-group vitamins and mineral nutrients.

Despite high feeding value, monocelled protein products are not widely used for animal feeding or human consumption due to the necessity of testing for toxicity and high protein costs.

Nonprotein nitrogenous compounds may also serve as a source of feed protein. Urea is the most widely used compound. World consumption of urea as a feed component is estimated at about 1.5×10^6 tonnes. In the US, Great Britain, and France urea is mostly included in formulated feed and used as a high-protein dry or liquid feed additive. The percentage of urea in formulated feed is about 1.5 (as calculated on the dry basis). In the USSR, the GDR, and Hungary urea is fed with silage, granulated formulated feed, pelleted straw, etc., in whatever form is the most economically expedient for a particular farm.

The use of urea for animal feeding should meet the requirements resulting from the physiological and biochemical nature of urea absorption in the rumen. Urea can be efficiently used provided the diets for ruminants contain sufficient amounts of energy, readily digestible carbohydrates (starch, sugar), mineral nutrients, and vitamins. The amount of nonprotein nitrogen must not exceed 30% of the total nitrogen requirements.

Protein concentrates obtained from the juice of green plants may also be a source of protein for feeding cattle, pigs, and poultry. In the USSR, Hungary, the US, France, Great Britain, Sweden, and other countries protein concentrate is produced from juice exuded during wet fractionation of green mass. The dehydrated mass is then preserved by usual methods. Alfalfa is currently the main raw material for the production of protein concentrates.

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