OCCASION

This publication has been made available to the public on the occasion of the 50th anniversary of the United Nations Industrial Development Organisation.

DISCLAIMER

This document has been produced without formal United Nations editing. The designations employed and the presentation of the material in this document do not imply the expression of any opinion whatsoever on the part of the Secretariat of the United Nations Industrial Development Organization (UNIDO) concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries, or its economic system or degree of development. Designations such as "developed", "industrialized" and "developing" are intended for statistical convenience and do not necessarily express a judgment about the stage reached by a particular country or area in the development process. Mention of firm names or commercial products does not constitute an endorsement by UNIDO.

FAIR USE POLICY

Any part of this publication may be quoted and referenced for educational and research purposes without additional permission from UNIDO. However, those who make use of quoting and referencing this publication are requested to follow the Fair Use Policy of giving due credit to UNIDO.

CONTACT

Please contact publications@unido.org for further information concerning UNIDO publications.

For more information about UNIDO, please visit us at www.unido.org

UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGANIZATION
Vienna International Centre, P.O. Box 300, 1400 Vienna, Austria
Tel: (+43-1) 26026-0 · www.unido.org · unido@unido.org

D01888

United Nations Industrial Development Organization

Distr.
GENERAL

ID/CONF.1/38
6 July 1967

ORIGINAL: ENGLISH

INTERNATIONAL SYMPOSIUM ON INDUSTRIAL DEVELOPMENT
Athens, 29 November-20 December 1967
Provisional agenda, Item 2

SECTORAL STUDIES:

FERTILIZER INDUSTRY

Presented by the Executive Director of the

United Nations Industrial Development Organisation areas. For instance, in the developing areas nitrogen production rose 20.4 per cent per year during the first five years of the 1960's, whereas in the developed areas it rose only 11 per cent per year. However, the total production in the developed areas is of course still much larger than in the developing areas.

11. In terms of consumption, the developing areas have outstripped the growth rate of the developed areas since 1960 in the case of phosphate and potash fertilizers, but not in the case of nitrogen fertilizers.

The boom in fertilizers

12. A world-wide boom in the construction of new fertilizer plants is now in progress, including nitrogen, phosphate and potash. At least 100 large-capacity fertilizer plants are under construction all over the world, but especially in the United States of America, Canada, western Europe, eastern Europe, the Soviet Union and Japan. This great development has been sparked first, by the rapidly increasing demand for fertilizers, secondly by the advent of improved technologies for the production of ammonia, urea, nitric acid, ammonium phosphates, granulated mixed fertilizers and other fertilizer materials, and thirdly by the discovery of important new sources of natural gas, phosphate rock and potash minerals.

13. The basic cause of this great upsurge in the demand for fertilizers is the rapidly increasing population of the world and the necessity of feeding and clothing these people. Up to 1950, the world's population had never increased at a rate of more than 25 million per year, but now it is increasing at a rate of over 70 million per year—and the rate is still growing. The demand for agricultural products and fertilizer is still further stimulated by the rising expectations of the peoples of the developing countries of Asia, Africa, and Latin America. The rising standards of living of western Europe, Japan and the socialist countries are also contributing factors. Unfortunately, the developing countries are largely being bypassed in this great boom in fertilizer plant construction. However, there are a few exceptions, such as Mexico, Taiwan, South Korea and South Africa.

Production and consumption of fertilizers up to 1975-1976

14. Table 3 and figures 2, 3 and 4 give projections of production and consumption of fertilizers in 1970-1971 and 1975-1976. The projections shown in table 3 and the three graphs represent the summation of separate graphical projections for the United States and Canada, the Union of Soviet Socialist Republics, western Europe, eastern Europe, Japan, Oceania, India, Asia (other than Japan, mainland China, North Korea and North Viet-Nam), Africa and Latin America.

15. The higher growth rate of the developing areas compared with the developed areas is clearly revealed in figures 2, 3 and 4. However, even in 1975-1976, production in the developing areas will still represent only 14 per cent of total world production of nitrogen, 10 per cent of world production of phosphate, and 5 per cent of world production of potash. In 1975-1976, the developed areas will still be surplus producers of all three nutrients, whereas the developing areas will have larger deficits of all three nutrients than they have now.

16. These conclusions are the result of a straightforward graphical analysis of past trends of production and consumption. There should be ample capacity to produce the quantities of plant nutrients shown in table 3. The well-known report of the Tennessee Valley Authority (TVA). <u>Estimated World Fertilizer Production Capacity as Related to Future Needs</u>, February 1966 gives capacities for 1970 as follows (in thousand metric tons):

/...

	Estimated fertilizer production in 1970-1971 (from table 3)	TVA estimate of capacity, excluding non-fertilizer capacity and also excluding mainland China
N	30,400	43,000
P_2O_5	20,700	28,000
K_2O	18,000	26,000
Total:	69,100	97,000

17. The estimates of capacity reported by TVA represent only a statement of intentions for 1970 by Governments and industrial firms, so that those capacities may or may not actually come into existence. If they should in fact materialize, there would be considerable economic pressure to increase production and consumption to match capacity more nearly.

Raw materials for fertilizer production

18. The principal raw materials for fertilizer production are: Hydrocarbons (as sources of hydrogen), including natural gas, petroleum and various petroleum fractions, and coal and lignite; phosphate rock; potash, and sulphur.

19. Hydrocarbon raw materials are widely distributed throughout the world. Most of the larger countries have one or more of them, although some areas are more richly endowed than others. The largest deposits of natural gas and/or petroleum in the developing countries are located in Iran, Iraq, Saudi Arabia, Kuwait, Libya, United Arab Republic, Algeria, Nigeria, Pakistan, Indonesia, Brunei, Burma, Mexico, Trinidad, Brazil, Argentina, Chile, Peru, Colombia, Bolivia and Venezuela. Coal and/or lignite are located in many countries, although gaseous or liquid fuels are much to be preferred to solid fuels for ammonia production.

/...

20. Phosphate minerals in substantial quantities are found in the following developing countries and territories: Morocco, Tunisia, Algeria, United Arab Republic, Jordan, Israel, North Viet-Nam, South Africa, Togo, Senegal, Spanish Sahara, Uganda, Brazil and Peru.

21. Potash deposits are much less common in the developing countries, being found in substantial amounts only in Ethiopia, Congo (Brazzaville) and Peru. In addition, Israel and Jordan have significant potash reserves in the form of lake brines.

22. Sulphur is available and utilizable in various forms, including elemental sulphur, pyrites, by-product sulphur dioxide from non-ferrous metal smelters, and gypsum/anhydrite. The subject is too complex to be discussed in this paper. However, it may be pointed out that, whenever and wherever electricity is cheap enough in relation to the cost of sulphur, sulphur can be replaced by electricity in the production of fertilizers. Electrothermal phosphorus can replace sulphur entirely in the production of phosphoric acid and phosphate fertilizers. Ammonium sulphate is a declining fertilizer and, in fact, would not be needed at all in view of all the other nitrogen fertilizers available. However, some sulphur will always be needed in fertilizers as a secondary plant nutrient.

23. Tables 4, 5 and 6 give an analysis of the developing countries in terms of the availability of natural gas, phosphate minerals and potash minerals in relation to their needs for nitrogen, phosphate and potash fertilizers. They indicate that there are good prospects for the development of nitrogen and phosphate fertilizer industries in many developing countries, but that potash minerals are very scarce in those countries. Several of the developing countries, such as India, Philippines, Turkey, Thailand, South Korea, North Korea and the Republic of Viet-Nam have none of the fertilizer raw materials in significant quantities. However, many of these countries have supplies of naphtha and/or refinery gas from their domestic oil refining industries which can be substituted for natural gas in ammonia production.

/...

Fertilizer targets for developing countries

24. *Per capita* consumption of fertilizers varies greatly among countries, as illustrated by the following data for 1965-1966:

	Kg N	Kg P_2O_5
Denmark	40	26
Netherlands	25	9
United States of America	24	17
United Kingdom	13	8
China (Taiwan)	11	2.9
Union of Soviet Socialist Republics	10	6.4
United Arab Republic	10	1.6
Japan	8	5.5
South Africa	5.5	6.6
China (mainland)	1.4	0.5
India	1.2	0.3
Brazil	0.7	1.2
Nigeria	0.03	0.02

25. There are similar variations in fertilizer consumption per hectare. Figures 5 and 6 show the largest *per capita* consumption of nitrogen and phosphorus fertilizers in the developing countries.

26. From the standpoint of economic planning, *per capita* fertilizer consumption is more significant than fertilizer consumption per hectare; since a given quantity of fertilizer will yield a certain amount of additional food or other agricultural product more or less independently of the amount of land on which the fertilizer is used. But of course this applies, even approximately, only within limits. Fertilizer usage per hectare has agronomic significance, but *per capita* fertilizer consumption has the greater economic significance.

/...

27. It is therefore suggested that, as a minimum target, all the developing countries should begin to plan now for *per capita* fertilizer consumption in 1975 along these lines: 10 kg N, 5 kg P_2O_5. These are, of course, very rough targets, and there would have to be considerable modifications for individual countries depending on types of crops, rainfall, soil analysis etc. Table 7 summarizes these suggested targets for all the developing countries with over 10 million population in 1975 (except mainland China, North Korea and North Viet-Nam).

/...

Table 1. World consumption of fertilizers

(In 000 metric tons)

	N	P_2O_5	K_2O	Total
1930-1931	1,499	2,986	1,959	6,444
1931-1932	1,237	2,403	1,508	5,148
1932-1933	1,205	2,467	1,549	5,221
1933-1934	1,267	2,780	1,956	6,003
1934-1935	1,592	2,974	2,281	6,847
1935-1936	1,969	3,104	2,432	7,505
1936-1937	2,147	3,399	2,707	8,253
1937-1938	2,485	3,678	2,960	9,123
1938-1939	2,670	3,637	2,904	9,211
1945-1946	2,025	3,375	2,100	7,500
1946-1947	2,568	4,368	2,677	9,613
1947-1948	3,109	5,017	3,104	11,230
1948-1949	3,330	5,497	3,540	12,367
1949-1950	3,639	5,864	3,994	13,497
1950-1951	4,191	6,208	4,514	14,913
1951-1952	4,534	6,273	5,006	15,813
1952-1953	5,218	6,639	5,392	17,249
1953-1954	5,805	7,192	6,053	19,050
1954-1955	6,510	7,540	6,260	20,310
1955-1956	6,795	7,980	6,780	21,555
1956-1957	7,285	8,280	7,170	22,735
1957-1958	7,870	8,530	7,420	23,820
1958-1959	8,775	9,050	7,915	25,740
1959-1960	9,150	9,630	8,225	27,005
1960-1961	10,200	9,845	8,465	28,510
1961-1962	11,030	10,435	8,635	30,100
1962-1963	12,415	11,155	9,285	32,855
1963-1964	13,920	12,250	10,050	36,220
1964-1965	15,165	13,695	11,000	39,860
1965-1966	17,390	14,525	12,145	44,060
1970-1971	28;200	20,300	17,000	65,500
1975-1976	44,000	27,600	23,500	95,100

Note: Data do not include mainland China, North Korea or North Viet-Nam

Source: FAO Monthly Bulletin of Agricultural Economics and Statistics, February 1962, for years 1930-1931 to 1953-1954.
FAO Production Yearbooks (annual), for years 1954-1955 to 1965-1966.
Projections for 1970-1971 and 1975-1976 obtained by summation of separate graphical projections for the United States and Canada, USSR, western Europe, eastern Europe, Japan, Oceania, India, Asia (other than Japan, mainland China, North Korea and North Viet-Nam), Africa, Latin America.

/...

Table 2. Comparison of growth rates of production and consumption of fertilizers in developed and developing areas, 1960-1961 to 1965-1966

(Percentages)

	Production			
	N	P_2O_5	K_2O	Total
Developed areas	11.0	7.7	8.6	9.3
Developing areas	20.4	10.7	23.5	16.8
Asia*	23.8	14.9	26.7	23.2
Africa	21.2	9.5	--	13.6
Latin America	13.8	6.9	0.0	11.9

	Consumption			
	N	P_2O_5	K_2O	Total
Developed areas	11.5	7.6	7.1	8.9
Developing areas	7.0	13.4	12.8	11.4
Asia*	7.0	18.0	17.1	12.7
Africa	9.3	6.7	14.9	9.9
Latin America	5.2	14.9	8.0	10.4

* Other than Japan, mainland China, North Korea and North Viet-Nam.

/...

Table 3. Production and consumption of fertilizers, 1965-1966, 1970-1971, 1975-1976

Nitrogen fertilizers (000 metric tons N)

	Production			Consumption			Surplus (deficit)		
	1965/66	1970/71	1975/76	1965/66	1970/71	1975/76	1965/66	1970/71	1975/76
Developed areas	17,425	27,000	40,000	14,675	23,000	35,000	2,750	4,000	5,000
Developing areas	1,430	3,400	6,600	2,715	5,200	9,000	(1,285)	(1,800)	(2,400)
Asia*	680	1,850	4,000	1,495	3,000	5,500	(815)	(1,150)	(1,500)
Africa	240	800	1,600	540	1,200	2,000	(300)	(400)	(400)
Latin America	510	750	1,000	680	1,000	1,500	(170)	(250)	(500)
World total	18,855	30,400	46,600	17,390	28,200	44,000	1,465	2,200	2,600

Phosphate fertilizers (000 metric tons P_2O_5)

	Production			Consumption			Surplus (deficit)		
	1965/66	1970/71	1975/76	1965/66	1970/71	1975/76	1965/66	1970/71	1975/76
Developed areas	13,855	19,000	25,000	12,990	17,500	23,000	865	1,500	2,000
Developing areas	930	1,700	2,900	1,535	2,800	4,600	(605)	(1,100)	(1,700)
Asia*	230	600	1,200	595	1,250	2,200	(365)	(650)	(1,000)
Africa	440	600	800	400	500	600	40	100	200
Latin America	260	500	900	540	1,050	1,800	(280)	(550)	(900)
World total	14,785	20,700	27,900	14,525	20,300	27,600	260	440	300

Potash fertilizers (000 metric tons K_2O)

	Production			Consumption			Surplus (deficit)		
	1965/66	1970/71	1975/76	1965/66	1970/71	1975/76	1965/66	1970/71	1975/76
Developed areas	13,110	17,300	23,500	11,225	15,500	21,000	1,885	1,800	2,500
Developing areas	330	700	1,200	920	1,500	2,550	(590)	(800)	(1,350)
Asia*	310	500	600	375	650	1,150	(65)	(150)	(550)
Africa	-	170	570	200	350	600	(200)	(180)	(30)
Latin America	20	30	30	345	500	800	(325)	(470)	(770)
World total	13,440	18,000	24,700	12,145	17,000	23,550	1,295	1,000	1,150

* Other than Japan, mainland China, North Korea and North Viet Nam. In all cases except in the production of potash fertilizers, India represents approximately 50 per cent of the amounts given for Asia.

Note: "Developed areas" includes United States, Canada, western Europe, eastern Europe, Soviet Union, Japan and Oceania. "Developing areas" includes Asia (except Japan, mainland China, N. Korea and N. Viet Nam), Africa, Latin America (South America plus all of North America except the United States and Canada).

/...

Table 4. Nitrogen fertilizer potentials in developing countries

Countries with substantial natural gas reserves and also large need for nitrogen fertilizer	Countries with substantial natural gas reserves but only small to moderate need for nitrogen fertilizer	Countries with large to moderate need for nitrogen fertilizer but little or no natural gas reserves*
Pakistan	Iran	India
Indonesia	Saudi Arabia	Philippines
United Arab Republic	Kuwait	Turkey
Nigeria	Iraq	Thailand
Mexico	Burma	South Korea
Brazil	Brunei	North Korea
Argentina	Libya	Republic of Viet-Nam
	Algeria	North Viet-Nam
	Venezuela	South Africa
	Colombia	
	Peru	
	Chile	
	Bolivia	
	Trinidad	

---

* However, most of the countries in this category have supplies of naphtha and/or refinery gas from domestic oil refineries which can be used as feedstock for production of nitrogen fertilizer.

/...

Table 5. Phosphate fertilizer potentials in developing countries

Countries with substantial phosphate mineral deposits and also large need for phosphate fertilizers	Countries or territories with substantial phosphate mineral deposits but only small to moderate need for phosphate fertilizers	Countries with large to moderate need for phosphate fertilizers but little or no phosphate mineral deposits
United Arab Republic	North Viet-Nam	India
South Africa	Jordan	Pakistan
Brazil	Israel	Indonesia
	Morocco	Philippines
	Tunisia	Thailand
	Togo	Burma
	Senegal	South Korea
	Algeria	North Korea
	Spanish Sahara	Republic of Viet-Nam
	Uganda	Iran
	Peru	Turkey
		Nigeria
		Mexico
		Argentina

/...

Table 6. Potash fertilizer potentials in developing countries

Countries with substantial potash deposits and also large need for potash fertilizers	Countries with substantial potash deposits but only small to moderate need for potash fertilizers	Countries with large to moderate need for potash fertilizers but little or no potash deposits
	Israel*	India
	Jordan*	Pakistan
	Ethiopia	Indonesia
	Congo (Brazzaville)	Philippines
	Peru	Thailand
		Burma
		South Korea
		North Korea
		Republic of Viet-Nam
		North Viet-Nam
		Turkey
		Nigeria
		South Africa
		Mexico
		Brazil
		Argentina
		Colombia

---

* Potash in Israel and Jordan is in the form of lake brines. Potential supplies are small in comparison with those of the major potash-producing countries, but still much larger than the domestic needs of Israel and Jordan.

/...

Table 7. Suggested minimum targets for consumption of fertilizers in developing countries in 1975

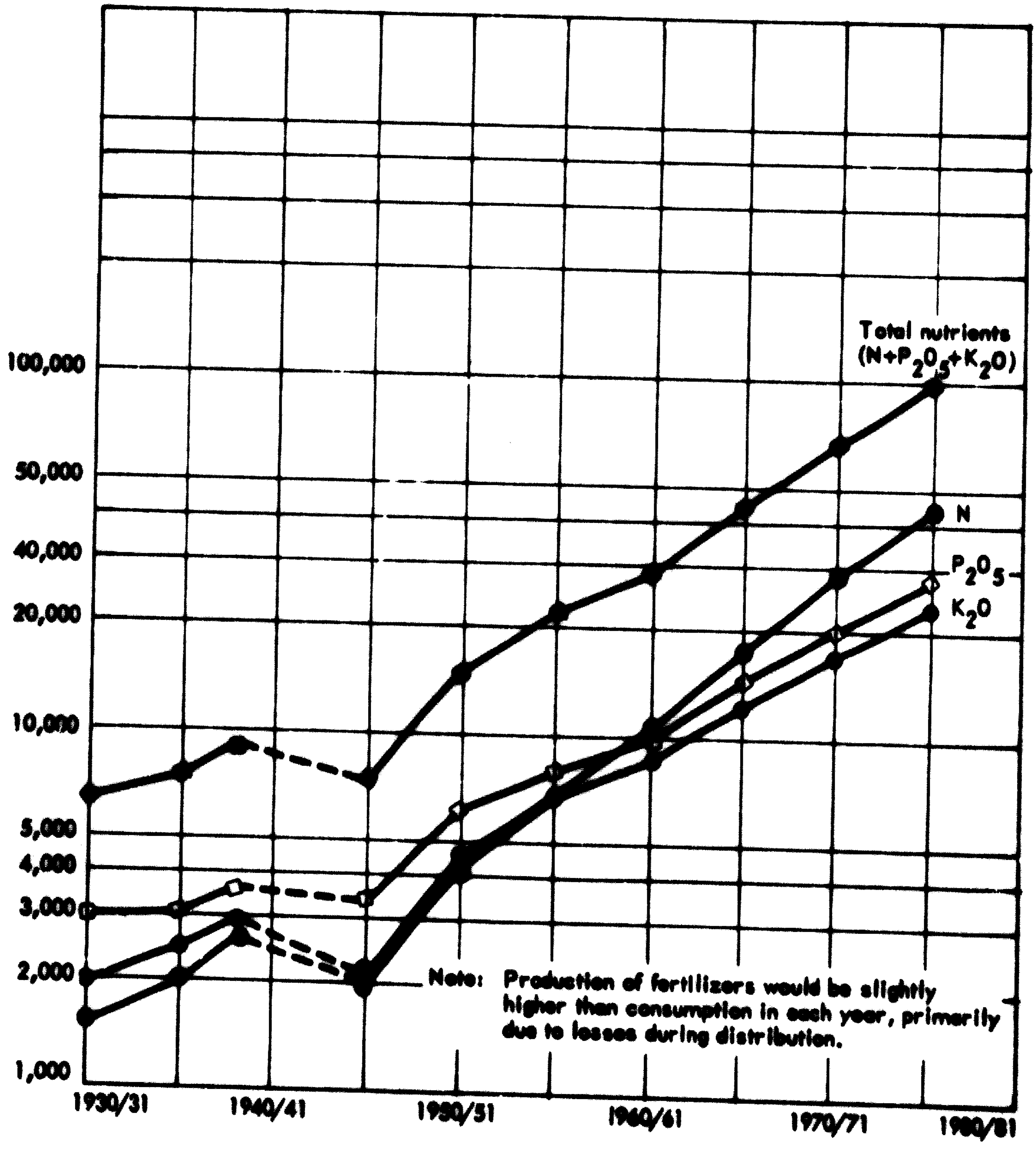
	Probable population, 1975 (in millions)	Suggested minimum targets for consumption of fertilizers in 1975		Actual consumption in 1965-1966	
		N(metric tons)a/	P_2O_5 (metric tons)b/	N(metric tons)	P_2O_5 (metric tons)
India	609	6,090,000	3,045,000	582,600	134,300
Pakistan	138	1,380,000	690,000	132,700	11,200
Indonesia	134	1,340,000	670,000	60,000	80,000
Brazil	113	1,130,000	565,000	60,000	100,000
Nigeria	81	810,000	405,000	2,000	1,400
Mexico	58	580,000	290,000	118,200	67,100
Philippines	46	460,000	230,000	58,000	30,000
Turkey	42	420,000	210,000	72,300	69,300
Thailand	42	420,000	210,000	18,000	10,000
United Arab Republic	40	400,000	200,000	300,000	50,000
South Korea	36	360,000	180,000	201,200	95,200
Burma	31	310,000	155,000	5,100	1,000
Iran	30	300,000	150,000	24,000	20,000
Argentina	27	270,000	135,000	25,000	5,000
Ethiopia	26	260,000	130,000	n.a.	n.a.
Colombia	24	240,000	120,000	60,000	60,000
South Africa	24	240,000	120,000	100,000	120,000
Republic of Viet-Nam	22	220,000	110,000	35,000	55,400
Afghanistan	20	200,000	100,000	n.a.	n.a.
Congo (Kinshasa)	19	190,000	95,000	1,000	300
Morocco	19	190,000	95,000	12,200	23,200
Algeria	17	170,000	85,000	17,000	16,000
Sudan	17	170,000	85,000	31,000	500
Ceylon	16	160,000	80,000	42,500	900
Peru	16	160,000	80,000	64,200	14,100
Malaysia	15	150,000	75,000	40,500	6,500
China (Taiwan)	15	150,000	75,000	145,000	37,300
Venezuela	13	130,000	65,000	30,000	8,000
United Republic of Tanzania	13	130,000	65,000	2,000	1,000

a/ Calculated on basis of 10 kg per capita.
b/ Calculated on basis of 5 kg per capita.

/...

Figure 1

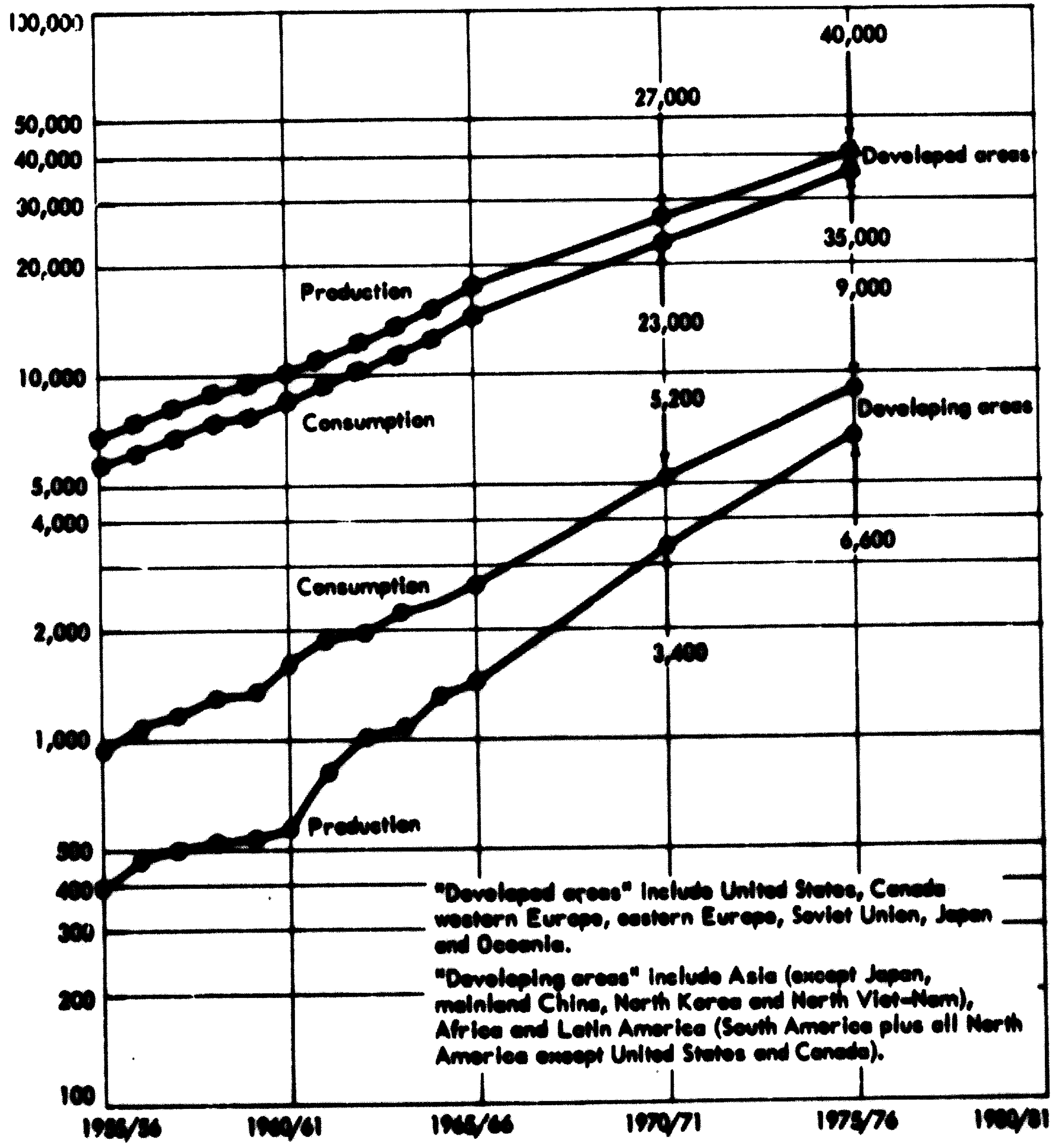
WORLD CONSUMPTION OF FERTILIZERS 1930/31 TO 1975/76
(in thousand metric tons of N, P_2O_5, K_2O)



Note: Production of fertilizers would be slightly higher than consumption in each year, primarily due to losses during distribution.

Figure 2

PRODUCTION AND CONSUMPTION OF NITROGEN FERTILIZERS IN DEVELOPED AND DEVELOPING AREAS
(in thousand metric tons N)

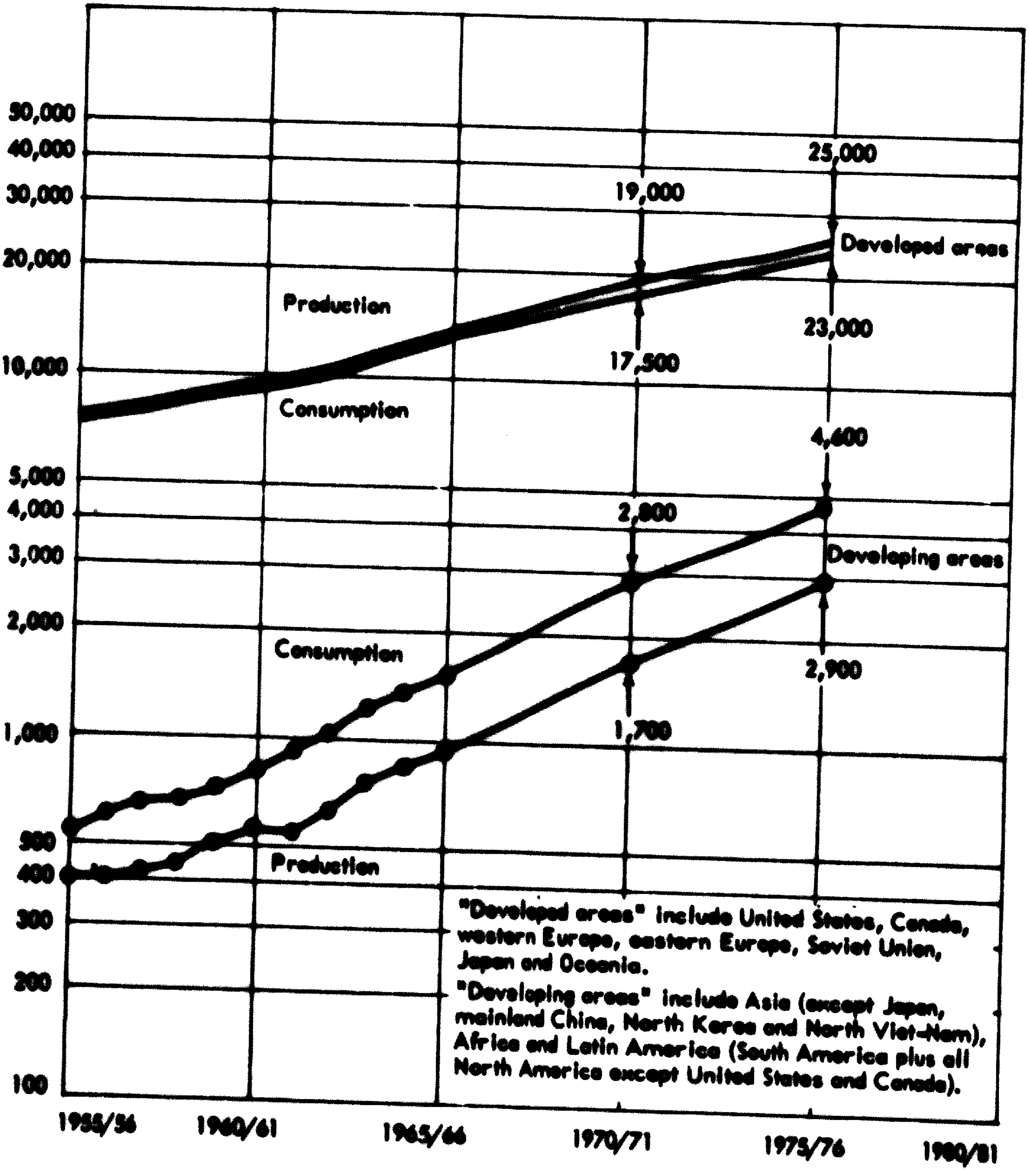


"Developed areas" include United States, Canada western Europe, eastern Europe, Soviet Union, Japan and Oceania.

"Developing areas" include Asia (except Japan, mainland China, North Korea and North Viet-Nam), Africa and Latin America (South America plus all North America except United States and Canada).

Figure 3

PRODUCTION AND CONSUMPTION OF PHOSPHATE FERTILIZERS IN DEVELOPED AND DEVELOPING AREAS
(in thousand of metric tons P_2O_5)



"Developed areas" include United States, Canada, western Europe, eastern Europe, Soviet Union, Japan and Oceania.

"Developing areas" include Asia (except Japan, mainland China, North Korea and North Viet-Nam), Africa and Latin America (South America plus all North America except United States and Canada).

Figure 4

PRODUCTION AND CONSUMPTION OF POTASH FERTILIZERS IN DEVELOPED AND DEVELOPING AREAS
(in thousand metric tons K_2O)

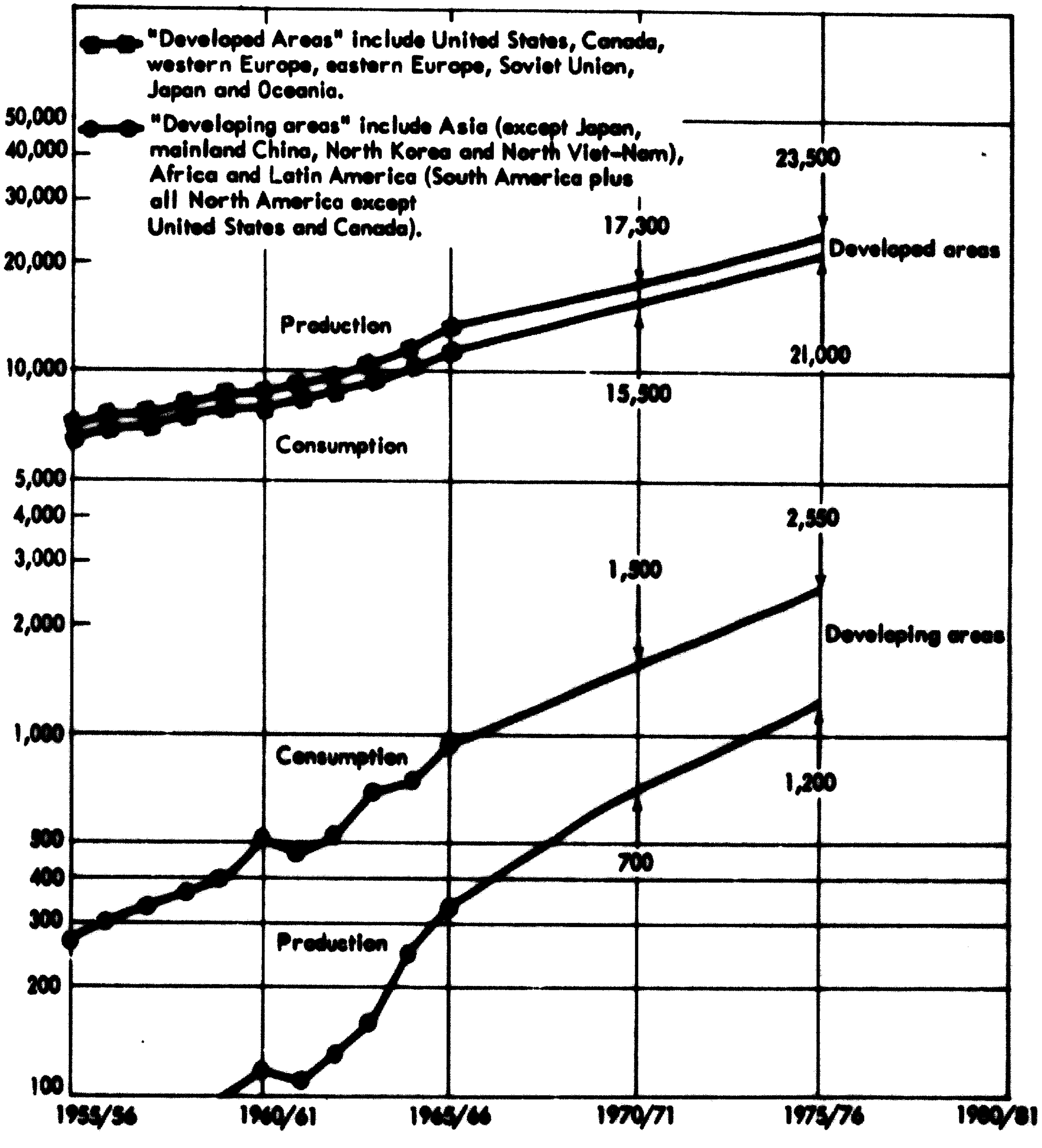
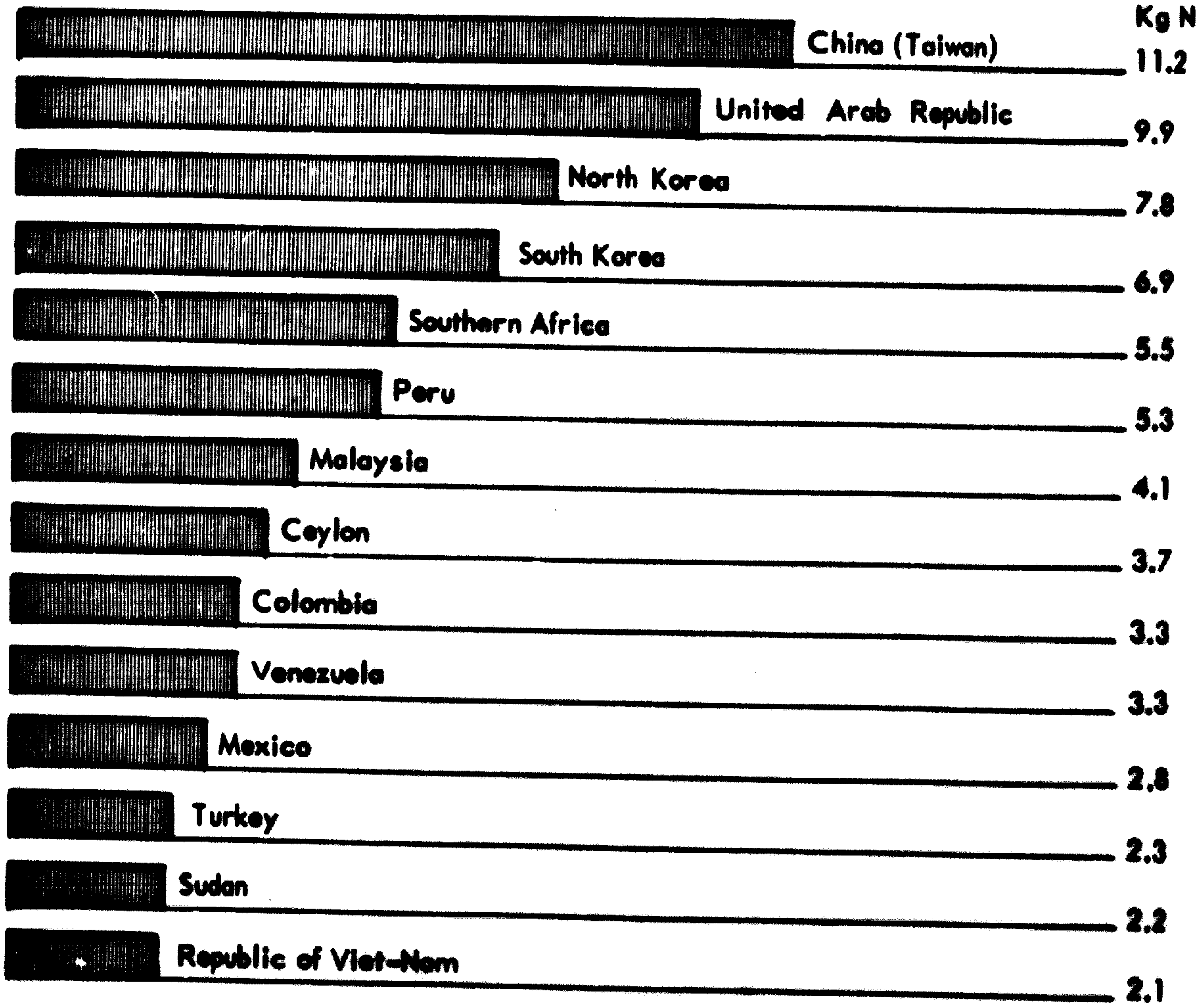


Figure 5

PER CAPITA CONSUMPTION OF NITROGEN FERTILIZERS IN DEVELOPING COUNTRIES, 1965 - 1966*

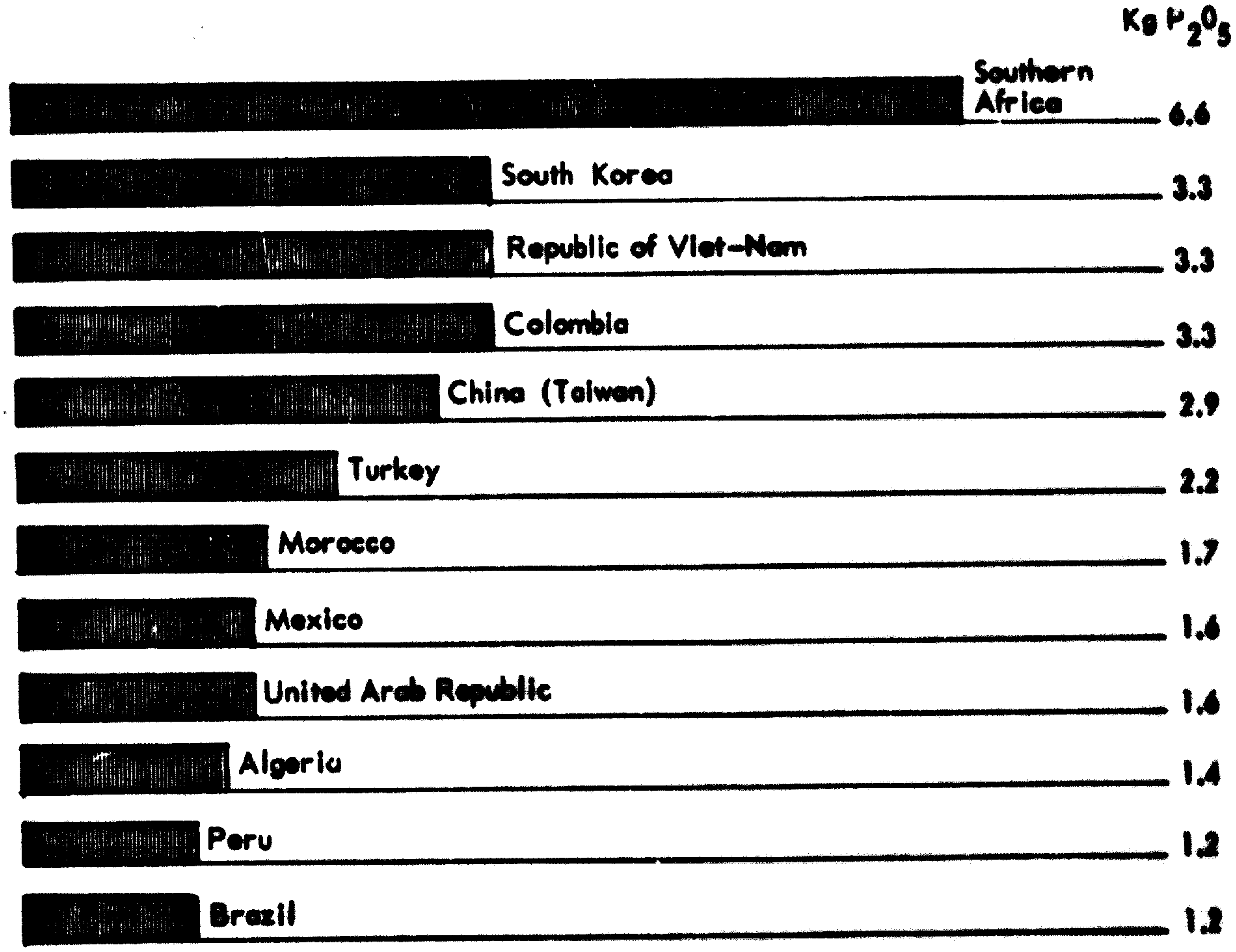


* Similar data for some other large developing countries are:

Mainland China	1.5
India	1.2
Pakistan	1.1
Indonesia	1.1
Brazil	0.6
Nigeria	0.7
Philippines	1.7
Thailand	0.6
Burma	0.2
Iran	1.0
Argentina	1.1

Figure 6

PER CAPITA CONSUMPTION OF PHOSPHATE FERTILIZERS IN DEVELOPING COUNTRIES, 1965 - 1966*



* Similar data for some other large developing countries are:

Mainland China	0.5
India	0.3
Pakistan	0.1
Indonesia	0.8
Nigeria	0.02
Philippines	0.9
Thailand	0.3
Burma	0.04
Iran	0.8
Argentina	0.2

II. NITROGEN

Introduction

28. Adequate supplies of nitrogen in appropriate agricultural forms are essential to healthy plant life and hence to mankind. Nitrogen fertilizer manufacture, principally based on synthetic ammonia, has become a major world industry measured in tens of millions of metric tons annually; and a continued growth is foreseen to meet the needs of a world population which will increase from some 3,000 million to at least 6,000 million by 2000 A.D.

29. A principal characteristic of the industry is the rapid transition to large and costly plants which are often integrated with feedstock sources such as coal, steel, oil and gas industries, as well as with phosphate fertilizer and chemical plants. The advent of suitable bulk marine transportation is in some cases creating a locational trend towards sources of available, low-cost feedstocks (especially natural gas), and this may become a future characteristic of nitrogen fertilizer manufacture.

30. These features and trends present numerous problems to the industry in developed countries, and create additional difficulties in many developing nations because of size, large capital requirements, shortages of skilled manpower and, in particular, the need for adequate transportation, distribution and marketing networks, and consumer-purchasing ability. Accordingly, it becomes essential to evaluate each envisaged project carefully and impartially.

Evolution of the nitrogen fertiliser industry

General

31. Directly or indirectly, plants provide all the food required by mankind. In their turn, plants have their specific input needs such as water and various minerals. At least sixteen elements have been identified as essential for plant growth and three—nitrogen, phosphorus and potassium—

/...

Contents

Page

I. General review

II. Nitrogen

III. Phosphates

/...

are required in sufficiently large quantities to warrant their being called primary nutrients.

32. The effects of nitrogen on plants include accelerated growth and increased yields of leaf, fruit and seed. A deficiency is soon evident from a yellowing and shrivelling of leaves. The initial response to nitrogen fertilizer is usually so favourable that the possible need for other plant nutrients is sometimes masked. However, the ultimate benefit of any nutrient depends on an adequacy of all the other essential elements; therefore a well-balanced fertilizer programme is imperative in every case.

33. Although surface plants, with the exception of a few, such as legumes of the clover or alfalfa class, are surrounded by atmospheric nitrogen, they are unable to "fix" or convert that gas into available compounds because of its extreme inertness. Consequently, nitrogen is mostly supplied through the soil in some soluble form. In a natural, ecological cycle, plant and animal wastes are converted by bacteria into nitrogen salts, which are again taken up by plant roots. This is a slow process, which is upset by cropping. Hence chemical compounds containing nitrogen and other necessary elements must be added to the soil to maintain the growth cycle.

Types of nitrogen fertilizers

34. Early nitrogen-containing fertilizers were of organic origin, for example, plant stalks, leaves, animal blood, carcasses, excreta. However, their low nutrient contents (e.g., 2 per cent N for cow manure) and limited supplies meant that other sources had to be found to meet the mounting population needs of the last century. Fortunately, ammonium sulphate produced from coal-gas plants and sodium nitrate imported from Chile became available and met requirements until the First World War, when large military needs led to the production of synthetic ammonia in Germany.

35. Later, ammonia synthesis plants were built on a world-wide basis, together with units for converting ammonia to derivatives such as ammonium nitrate, ammonium sulphate and urea. Thus, synthetic ammonia, containing

82 per cent N (and made by combining atmospheric nitrogen with hydrogen produced mainly from natural gas or petroleum feedstocks) has become the key material in the nitrogen fertilizer industry of today. Organic nitrogene materials, by-product ammonium sulphate, calcium cyanamide and Chilean nitrate now represent only about 10 per cent of the total nitrogen fertilizer consumed; the balance is all derived from man-made ammonia.

World nitrogen fertilizer demand and supply

Historical growth

36. The historical world nitrogen fertilizer pattern has undergone major changes in the twentieth century, as indicated in the data appearing below.

Historical pattern of world nitrogen production
(000 metric tons N)

Year	As Chilean nitrate, coke oven ammonia, calcium cyanamide	As synthetic ammonia	As total N
1913-1914	730	4	734
1938-1939	996	904	1,900
1963-1964	1,782	16,178	17,960

Future nitrogen needs

37. Based on calculations of the Food and Agriculture Organization (FAO), world nitrogen fertiliser requirements needed to maintain even minimum current dietary standards are shown below. On this basis, failure to meet these needs will result in hunger in those parts of the world where fertiliser supplies (or corresponding food availability) fall below the indicated levels.

Estimated minimum world nitrogen needs
(Million metric tons N)

Region	1965	1970	1975	1980
Asia, Africa, Latin America	5.29	11.73	15.65	20.93
United States of America, Canada	4.95	8.03	10.50	13.74
Rest of world	8.50	12.49	16.06	20.21
Total:	18.74	32.25	42.21	54.88

Material mix

38. The material mix is also undergoing significant changes, as high-analysis fertilisers such as urea and ammonium phosphate increase in popularity, and as the use of liquid fertilisers continues to grow. The following figures indicate possible trends in the nitrogen material mix pattern during the next few years.

Estimated world nitrogen material mix pattern

Material	Percentage of total N	
	1962	1970
Ammonium sulphate	24	14
Ammonium nitrate	28	25
Sodium nitrate	3	2
Calcium nitrate	4	3
Cyanamide	2	2
Urea (solid)	9	15
Other forms (solids) *	12	18
Other forms (solutions)	17	20
Organic materials	1	1
	100	100

* Including ammonium phosphates and nitrophosphates.

Feedstock supplies

39. Since most nitrogen fertilizers are based on anhydrous ammonia made from natural gas and liquid hydrocarbons, raw material availability, on the basis of current ammonia technology, must be examined in terms of those feedstocks, since it may be assumed that ample atmospheric nitrogen will always be available.

40. Calculations indicate that the projected nitrogen requirements to 1985, based on total world agricultural and industrial needs for ammonia, amount to some 125 million metric tons. On the assumption that one-half is made from natural gas and the other half from liquid hydrocarbons, this total corresponds to about 2 per cent of presently known natural gas reserves and a negligible proportion of proven world petroleum reserves. Thus no raw material shortages for nitrogen fertilizers are foreseen, even without taking into consideration the enormous reserves of coal lignite and oil shale and the hydrogen present in the waters of this planet.

Nitrogen fertilizers and the developing countries

Production costs

41. When considering the production of nitrogen fertilizers in a developing country, several factors must be examined. For example, is the current or future domestic demand big enough to justify a large, economically sized ammonia(and derivatives) plant, or can such products be imported at lower cost? Secondly, is an economic source of feedstock available? Thirdly, can an inter- or intra-regional export trading pattern be developed to support a large plant? Fourthly, could the required capital (often in the $25 million to $50 million range) be more advantageously spent on other needed projects?

42. Plant size has a major influence on production costs; with natural gas at $0.20 per million BTU, ammonia made in a unit producing 200 metric tons per day may cost $30 to $35 per metric ton, whereas, if made in a plant

/...

producing 1,000 metric tons per day, the probable cost would be about $17 per metric ton. Similarly, based on an output of some 370 metric tons per day, for example, the ammonia costs corresponding to natural gas costs of $0.10 and $0.50 would be about $26 and $42 respectively.

43. As a result of these economic factors, there is a locational pull now taking place towards low-cost sources of feedstock, especially natural gas, and in favour of very large ammonia plants in the 1,000 to 2,000 metric tons per day category, built near gas fields or seaports. Ammonia (and derivatives) made under these conditions can frequently be transported in special boats and delivered to consumer points thousands of miles distant, at prices competitive with, or lower than, locally made nitrogen fertilizer based on a small or medium-sized plant using relatively high-cost fuel. Therefore each possibility of making nitrogen fertilizers, whether in a developing or in a developed country, must be carefully examined on the basis of the various alternatives now available.

44. It should be added that the switch to large ammonia plants (based on centrifugal compression and self-supporting steam energy) in the United States and Europe is so recent that only a few of the sixty or so plants are yet in operation, and several minor design or equipment problems in some of these are still in process of solution. One cause of delays and start-up difficulties has been an acute shortage of experienced, skilled labour and personnel. Consequently, any prospective builder of a large nitrogen fertilizer plant, whether in a developing or a developed country, is well advised to check the accumulated experience of prospective suppliers and sub-contractors. This is particularly important for developing areas, where plant modifications and limited availability of spare parts could create serious delays and additional costs.

/...

Summary and conclusions

45. World demands for nitrogen fertilizer will continue to climb in the foreseeable future. Ammonia is the key product for which no raw material shortages are foreseen.

46. The industry is rapidly becoming based on large and costly plants which necessitate correspondingly large and complex supply and distribution networks. For maximum benefit, it is often desirable to set up intra-industry and inter-industry links. No imminent, fundamental changes in technology are foreseen, although continued process and product research is likely to reduce manufacturing costs and develop more advanced products.

47. The increased availability of large marine transportation facilities is already affecting established raw material production and sales patterns in many countries, domestically and internationally. Such changes may be expected to increase and they may be to the advantage of many developing countries with limited basic resources.

48. Principal characteristics of the world nitrogen fertilizer industry include: an advanced state of technical development; a transition to large and costly plants; intra-industry and inter-industry links becoming increasingly important; a locational movement towards low-cost raw material sources; integration with bulk transportation networks.

49. These characteristics create additional problems for many developing nations, including the feasibility of domestic production versus importation, and appropriate timing. Accordingly, a careful and impartial evaluation of each potential project is essential to avoid wasting resources and scarce foreign exchange on premature or uneconomic units.

/...

III. PHOSPHATES

Introduction

50. The importance of phosphorus in agricultural crop production and human nutrition is well known. However, there is a tendency in many developing countries to reduce the use of phosphorus (P_2O_5) relative to nitrogen (N). This may be harmless in soils rich in phosphorus, but in others the continued use of nitrogen without P_2O_5 will soon exhaust the supply of P_2O_5 in the soil and disastrous crop failures may ensue. Initial response to nitrogen fertilizers is often more spectacular. The average world proportion of N to P_2O_5 to K_2O used in 1965-1966 is 1:0.8: 0.7. The ratios in developed countries such as Japan and the United States for the same period are as follows:

United States of America	1: 0.7: 0.6
Japan	1: 0.7: 0.8

In developing countries such as India, the United Arab Republic and Mexico, on the other hand, the ratios are as follows:

India	1: 0.3: 0.13
United Arab Republic	1: 0.18: 0.004
Mexico	1: 0.57: 0.05

General trends

51. A survey made in 1965 by the United States Tennessee Valley Authority (TVA) of the present (1965) and future (1970) capacity of the world phosphate industry has been updated and is shown in table 8 and figure 7.

/...

FIGURE 7

Phosphate Industry Capacity and Fertilizer Production

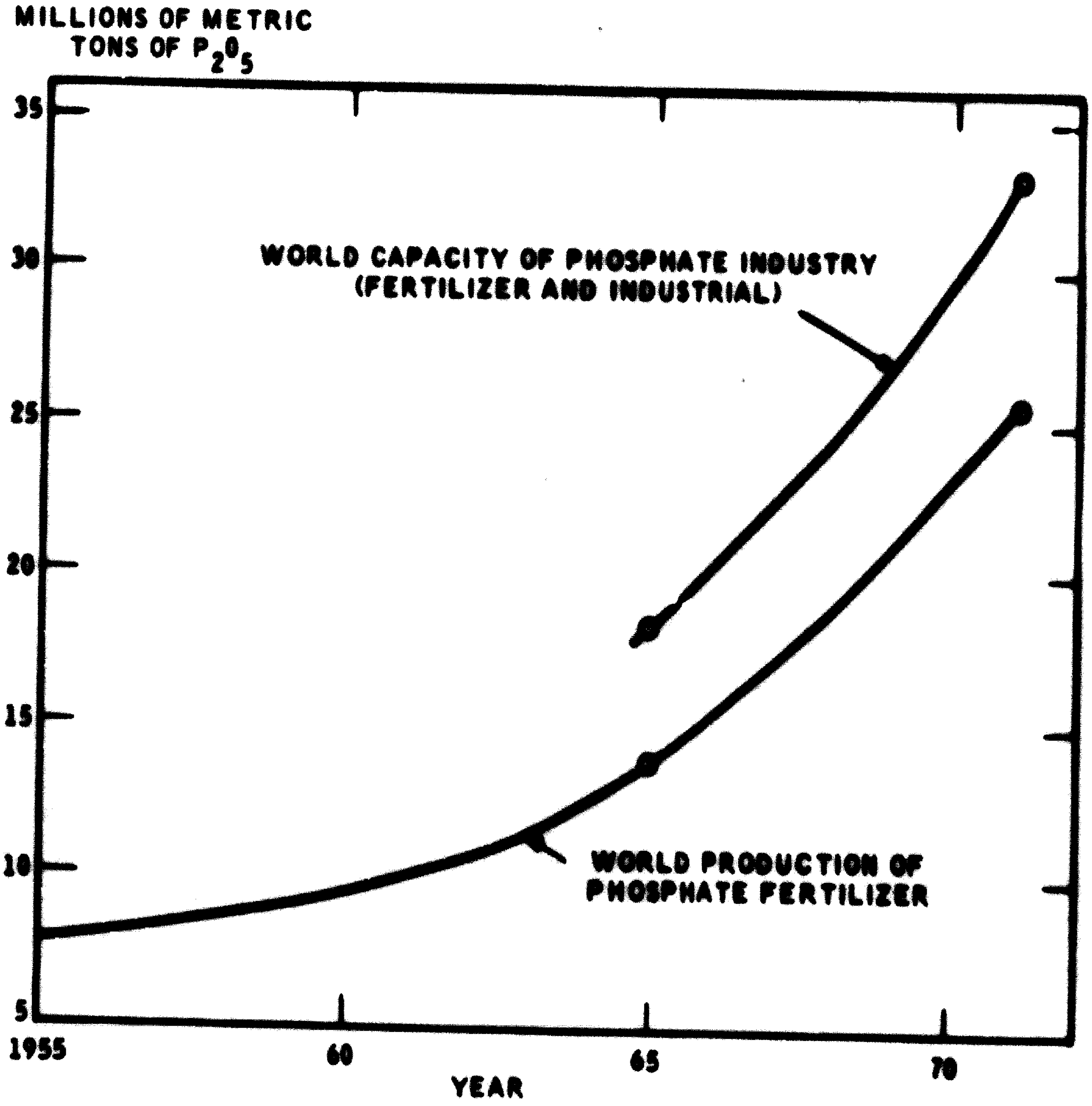


Table 8. Estimates of present and future capacity of the world phosphate industry

	Fertilizer production 1965 [a]	Estimated phosphate industry capacity, fertilizer and industrial 1965	1966	1971
	(In million metric tons P_2O_5 per year)			
Europe				
Western	4.34	5.53	5.92	7.72
Eastern[b]	2.81	2.21[c]	2.88	5.94
Asia	1.02	1.56	2.13	3.61
Africa	0.30	0.67	0.84	1.71
North America	4.02	6.33	7.89	10.29
Latin America	0.18	0.44	0.47	2.31
Oceania	1.13	1.06[d]	1.48	1.91
Total:	13.80	17.80	21.61	33.49
Possible fertilizer production, capacity x 0.90 x 0.85[e]		13.62	16.53	25.62

[a] Fertilizer year ended 30 June 1965.
[b] Including Soviet Union.
[c] Capacity of fourteen plants not reported.
[d] Capacity of one plant not reported.
[e] Assuming 90 per cent production and 85 per cent of phosphate used for fertilizer.

52. The estimated capacity of the world phosphate industry increased from 17.8 million metric tons of P_2O_5 in 1965 to 21.6 in 1966 and is expected to increase to 33.5 million tons in 1971. The latter figure includes an assumed USSR capacity of 3.6 million metric tons of P_2O_5 and an arbitrary allowance for mainland China. It does not include phosphate rock used directly on soil after being finely ground but without chemical processing. In 1965, ground phosphate rock used was 5.8 million metric tons, equal to about 1.8 million metric tons of P_2O_5. The FAO figure for P_2O_5 consumption in 1965-1966 is 14.5 million metric tons compared to 13.6 million metric tons in 1964-1965,

/...

an increase of 6.6 per cent.

53. The growth rate of the world phosphate fertilizer industry in recent years has been about 12 per cent per year. If the 1971 projected production of 25.6 million metric tons is attained, the growth rate will be slightly over 10 per cent per year.

Higher analysis products

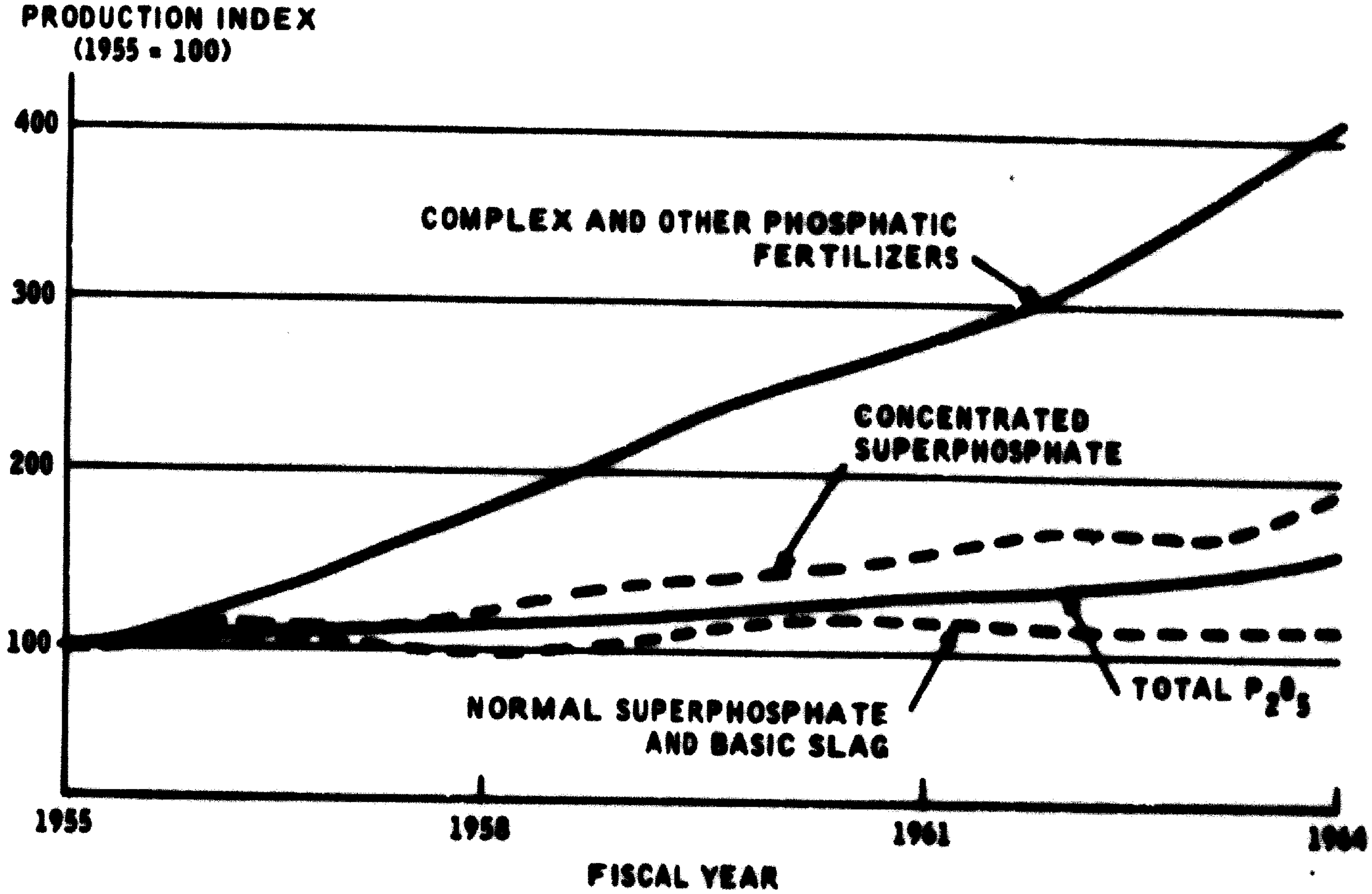
54. There is a strong trend in the world towards high-analysis phosphate fertilizers. The developing countries should whenever possible adopt this trend because it reduces the bagging, transport and storage costs per unit of P_2O_5. In 1955, the lower analysis materials, normal (single) superphosphates and basic slag supplied about 81 per cent of the world's phosphate fertilizers. By 1965, these products constituted only 58 per cent of the total. Figure 8 shows that the increase in normal superphosphate was about 20 per cent, whereas concentrated superphosphate approximately doubled and "complex" or "multi-nutrient" fertilizers (mainly ammonium phosphate and nitrophosphate) quadrupled.

55. The most popular of the concentrated phosphate fertilizers are concentrated superphosphate and ammonium phosphate. Both require phosphoric acid for their manufacture, mainly wet-process acid, which in turn require sulphur. Developing countries are already anxious about the world shortage of sulphur and its high price. In developing countries or regions where cheap electric power and phosphate rock are available, the electric-furnace method should be investigated. The capital cost for this method is quite high compared with that used in the wet-process phosphoric acid plant. Table 9 shows the distribution of phosphate fertilizer capacity by major types of products by 1971.

/...

/...

FIGURE 8
RELATIVE GROWTH IN PRODUCTION OF PHOSPHATIC FERTILIZERS
(WORLD)



CONCENTRATED
SUPERPHOSPHATE

Table 9. Distribution of 1971 phosphate fertilizer capacity among major types of products

Product	Percentage of world P_2O_5 capacity[a] in 1971
Normal superphosphate	30.2
Concentrated superphosphate	18.9
Complex fertilizers[b]	30.0
Basic slag	5.7
Other and unspecified phosphate fertilizers[c]	15.2

---

[a] Excluding USSR and mainland China.

[b] Includes ammonium phosphate, 20 per cent; nitrophosphates, 6 per cent; and unspecified types of complex fertilizers, 4 per cent.

[c] Includes phosphoric acid, for which no specific use has been determined.

56. The following tabulation shows typical grades and plant nutrient content of the leading phosphate fertilizers:

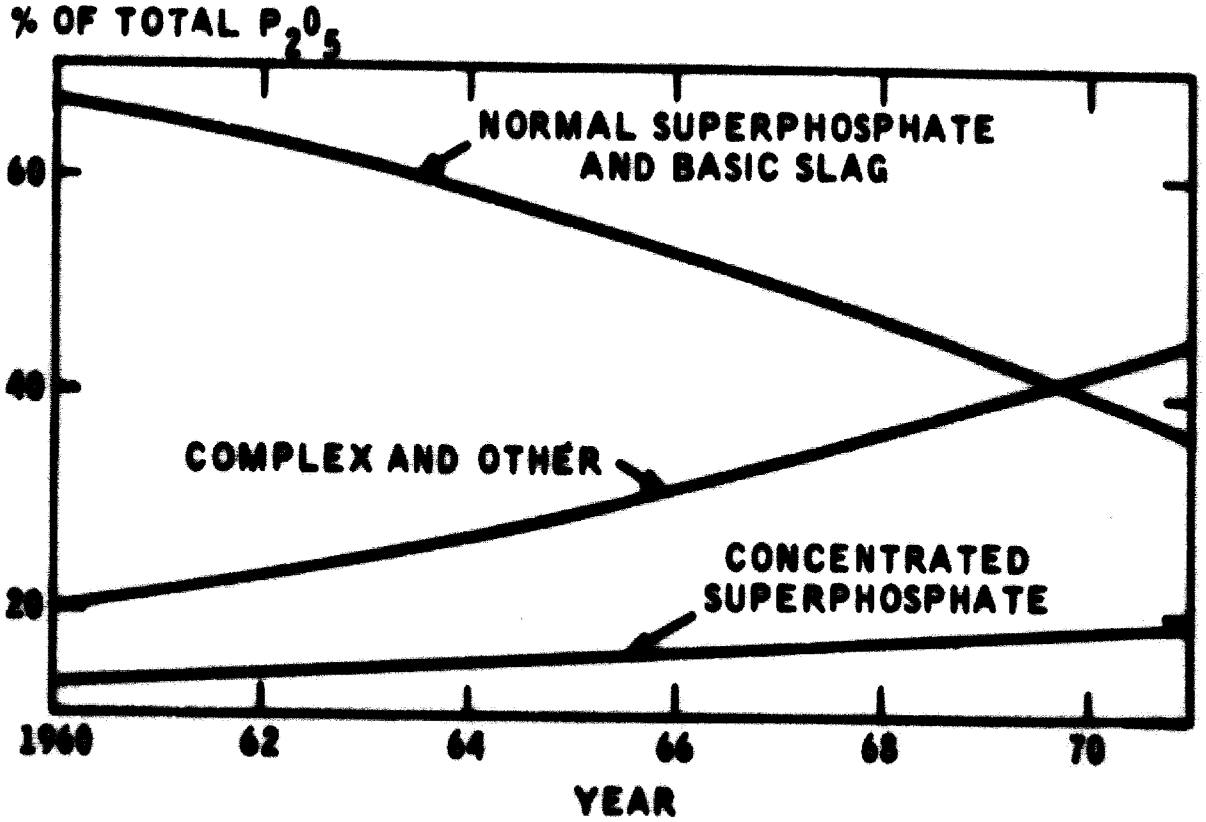
Material	Typical grade N	Typical grade P_2O_5	Typical grade K_2O	Concentration percentage plant nutrient content
Normal (single) superphosphate (SSP)	0	18	0	18
Concentrated (triple) superphosphate (TSP)	0	45	0	45
Ammonium phosphate (AP)	18	46	0	64
Nitrophosphate (NP)	20	20	0	40

Trend towards higher analysis phosphate fertilizers is shown in figure 9.

/...

FIGURE 9

TREND IN TYPES OF PHOSPHATE FERTILIZER



Trend towards integration of phosphate with nitrogen and production of "mixed" or multi-nutrient fertilizers

57. There is a growing tendency among farmers in developed countries to prefer to use phosphate in the form of multi-nutrient fertilizers rather than as a single nutrient. In developing countries, the farmer has to be educated to this approach. Some developing countries prescribe certain mixtures containing different N, P and K combinations, taking into account the analysis of soil and type of crops to be grown. Formerly, mixtures were made using straight fertilizers such as superphosphate, ammonium sulphate and potassium chloride. Often these ingredients were manufactured by different companies and shipped to a mixing plant where they were mixed and sometimes granulated. Such mixing and granulation entail additional expense. The modern practice is to manufacture mixed fertilizers in integrated plants. As a result, mixed fertilizers are not necessarily more expensive than straight fertilizers and may in fact be cheaper. Developing countries should develop the integrated approach so that the farmer receives in a single bag all the nutrients needed for the particular crop under particular soil conditions. This also saves the farmer time and labour.

Trend towards large-scale production units

58. There is a general trend in the phosphate fertilizer industry towards large-scale production units, resulting in a substantial reduction in cost per unit of output. Whereas ten years ago a wet process phosphoric acid plant producing 200 metric tons of P_2O_5 per day was regarded as a large plant, today plants are in operation capable of producing 600 metric tons per day in a single train of reactors, filter and evaporation system. Nitrophosphate plants capable of producing 1,500 tons per day are in operation and are part of a complex producing ammonia, nitric acid and straight nitrogen fertilizers. Electric-furnace phosphorus units of 70,000 kw capacity

/...

have been reported producing 140 tons of phosphorus per day, equivalent to 320 tons of P_2O_5.

59. Developing countries with large internal consumption should take advantage of the economy of scale in production. Where internal consumption is small, several countries in a region could co-operate to achieve such economy. Increasing the scale of operation should always be weighed against the cost of distribution of the product over wider market areas. There are also advantages in locating production facilities at the phosphate mine, since high-analysis phosphate fertilizers weigh less than the rock from which they are made.

Links with other sectors of industry

Phosphate rock

60. The only indispensable raw material for the production of phosphate fertilizer is phosphate rock. World consumption of phosphate rock in 1965 was about 63 million metric tons and is expected to reach 100 million by 1970.

61. Assuming that the 1971 production of phosphate fertilizer and industrial phosphate is 90 per cent of the estimated capacity and that the average recovery of P_2O_5 in processing is 90 per cent, about 33.5 million metric tons of P_2O_5 as phosphate rock will be required in 1971. To this must be added the phosphate rock used for direct application, which accounted for 1.8 million tons of P_2O_5 in 1965. Assuming no increase in rock for direct application, the 1971 rock requirement would be 35.3 tons of P_2O_5, which is equivalent to about 110 million tons of rock containing 32 per cent P_2O_5.

62. To meet the greatly increased demand for phosphate rock, steps are being taken to open new mines and to expand production of existing mines. In the United States of America, new mines have been opened in North Carolina and northern Florida and other deposits are being explored.

/...

Phosphate rock production is being expanded in Morocco, the United Arab Republic, Tunisia, Senegal, Togo, the USSR, South Africa and Jordan. New deposits have been found in many countries and territories, including India, Iran, Peru, Venezuela, Brazil, Spanish Sahara and Turkey. Known reserves are ample for several hundred years. The price of phosphate rock has remained steady except for a 10 to 15 per cent rise recently for higher grades.

63. There is extensive world trade in phosphate rock, since many countries have no known usable deposits. Nearly half of the phosphate rock produced enters into world trade, Europe (excluding the USSR) being the largest market. European imports totalled about 16 million tons in 1965. Japan, India and Australia are the largest importers outside Europe.

Sulphur and sulphuric acid

64. World consumption of sulphur (in all forms) was nearly 30 million metric tons in 1965 and of this total between 40 and 50 per cent was used for fertilizer production. About 70 per cent of the sulphur used for fertiliser production was used to make phosphate fertiliser. Thus, the quantity of sulphur used to make phosphate fertiliser is roughly 9.5 million metric tons (30 x 45 per cent x 70 per cent). Since world production of phosphate fertiliser in 1965 was 13.8 million metric tons of P_2O_5, the ratio of sulphur to P_2O_5 was about 0.7.

65. On the above basis, the 1971 projected production of phosphate fertiliser (25.6 million metric tons of P_2O_5) will require 17.9 million tons of sulphur. If other sulphur uses grow at the current rate of 4 per cent per year, they will reach 26 million metric tons by 1971. The total sulphur demand will be 43.9 million metric tons, requiring an increased supply of nearly 14 million metric tons or an average rate of growth of 2.3 million metric tons per year.

66. In 1965 (calendar year), the consumption of sulphur was 23.3 million

/...

metric tons (excluding U.S.S.R., Eastern Europe, and mainland China). Production was 22.4 million metric tons. The difference was made up by withdrawal from stockpile. Estimated usage for phosphate and nitrogen fertilizers and for other purposes are as follows:

	Million metric tons of sulphur
Phosphate fertilizers	7.7
Ammonium sulphate and sulphate nitrate	3.0
Other uses	12.6
	23.3

The estimated sulphur demand in 1971 is as follows:

	Million metric tons
Phosphate fertilizers	14.7
Ammonium sulphate and sulphate nitrate	4.3
Other uses (4 to 5 per cent growth per year)	16.0 to 16.9
	35.0 to 35.9

67. McCune and Harre (TVA) estimate that the 1971 sulphur-producing capacity of the world (excluding eastern Europe, the USSR and mainland China) will be 32.3 million metric tons. Assuming sulphur production at full capacity, there will be a deficit of 2.7 to 3.6 million metric tons in 1971.

68. About one-half the world's supply of sulphur is in the form of elemental sulphur.

69. In 1964, the sources of the sulphur comprising world consumption were:

Sources	Million metric tons	Percentage of total
Elemental sulphur	14.2	51
Pyrites	8.3	30
Other sources*	5.2	19
	27.7	100

---

* Includes gypsum, anhydrite,smelter gas,refinery gas and miscellaneous sources.

/...

The world prospect is that supplies of elemental sulphur will continue to lag behind demand and that the price will reach the level at which sulphuric acid from pyrites and other sources will become competitive. Economic pressures will favour increased use of pyrites and other forms of sulphur and increased use of fertilizer processes that do not require sulphur.

Technology and economics of the phosphate industry

70. The technology of producing the following phosphatic fertilizers is well known: normal (single) superphosphate; concentrated (triple) superphosphate.

71. There are two basic methos in commercial use for the production of phophoric acid--the wet process, using sulphuric acid, and the furnace process. The estimated world capacity for production of wet process phosphoric acid will increase from 5.4 million metric tons of P_2O_5 in 1965 to 14.7 million metric tons in 1971. Furnace acid capacity is expected to increase also, particularly because of the world-wide shortage of sulphur and its rising prices. Because of the higher purity of the furnace acid, it is used extensively for the production of phosphates for detergents and other higher-value products. At the same time, 19 per cent of the electric-furnace phosphorus produced in the United States was used for fertilizer purposes, whereas 93 per cent of the wet process acid was used in fertilizer production. Much of the wet process acid is used for the manufacture of triple superphosphate and ammonium phosphate. However, in recent years, wet process phosphoric acid has become more of an article of commerce. The quality of the acid has been improved so that its handling and shipment are less difficult.

72. The hydrochloric acid process for making phosphoric acid is attracting attention and, where hydrochloric acid is in surplus, small projects based on this process have been built. Hydrochloric acid is used to digest phosphate rock instead of sulphuric acid, and the phosphoric acid formed is separated from the calcium chloride by means of an organic solvent which

/...

may be normal butyl or isoamyl alcohol. The solvent is separated from the acid and recycled to the process. The process was developed by Israel Mining Industries. A similar process was developed by Dow Chemical using tributyl phosphate as the solvent. The economics of this process depends on the cost of hydrochloric acid. In the United States, where hydrochloric acid costs around $70 per metric ton, and since nearly 2 metric tons of chlorine are required per metric ton of P_2O_5, it is obviously uneconomical. But where cheap by-product hydrochloric acid is available, the process has advantages.

Superphosphoric acid

73. Super phosphoric acid containing 76 per cent P_2O_5 is a liquid at room temperature and can be produced from elemental phosphorus at essentially the same cost per unit of P_2O_5 as the normal wet process phosphoric acid (54 per cent P_2O_5).

Ammonium phosphates

74. These may be produced as mono-ammonium (11-48-0) or di-ammonium (18-46-0) salts or mixtures of the two. They may be combined with ammonium nitrate, ammonium sulphate or urea.

Ammonium phosphate sulphate

75. When both phosphoric and sulphuric acids are used, products with analyses of 13-39-0 or 16-20-0 could be made.

Ammonium phosphate nitrate

76. When phosphoric and nitric acids are used, products with analyses 30-10-0, 27-14-0 and 25-25-0 are possible.

Urea-ammonium phosphate

77. Urea may be mixed with ammonium phosphate to produce products such as 29-29-0, 25-35-0, 38-13-0, or with potash 20-20-20, 25-15-15 or 15-30-15.

/...

Ammonium polyphosphate

78. Reaction of ammonia with superphosphoric acid yields a mixture of ammonium orthophosphate and polyphosphate, which is commonly called ammonium polyphosphate. Triammonium pyrophosphate, $[(NH_4)_3HP_2O_7]$ is the principal polyphosphate, although other pyrophosphates and tripolyphosphates are likely to be present.

79. At present, the only known large-scale production of solid ammonium polyphosphate is in the TVA plant. The grade of the TVA product is 15-60-0. It is made by reaction of furnace superphosphoric acid with anhydrous ammonia under elevated pressure and temperature (3 atm. and 210°C.). The product is discharged from the reactor as a fluid melt and is granulated in a pugmill. Since no moisture is present, drying is unnecessary. The pugmill product is cooled and screened; the oversize is crushed, and fines are recycled.

80. Ammonium polyphosphate of 12-60-0 grade has been made experimentally from wet-process phosphoric acid. As in the case of ammonium orthophosphates, the polyphosphate may be combined with urea, ammonium nitrate, or ammonium sulphate, and potash salts may be added to make a variety of multi-nutrient fertilisers.

81. Ammonium polyphosphate solutions are produced by several firms in the United States and Europe by ammoniation of superphosphoric acid and concurrent addition of water. The usual grades of the solution are 11-37-0 and 10-34-0. The solutions are used in the preparation of liquid mixed fertilisers.

Nitrophosphate

82. If phosphate rock is acidulated with nitric acid, the product will contain calcium nitrate and monocalcium phosphate. The hygroscopicity of calcium nitrate precludes general acceptance of this product. Nitric acid serves two purposes. It makes the phosphate soluble and it provides nitrogen

/...

LIST OF TABLES

/...

as a plant nutrient. In the Odda process, the calcium nitrate is removed by filtration. The calcium nitrate may be used as such or converted to ammonium nitrate. There are various other variations of this process. All are attracting world-wide attention owing to the fact that the processes do not involve the use of sulphur. The processes using sulphuric or phosphoric acid in conjunction with nitric acid, as well as those using ammonium sulphate addition or carbon dioxide addition have also become attractive.

83. Four processes are shown schematically in the flow diagram (Figure 10) and their comparative economics in table 10

(a) Odda Smeltwerke process - nitrophosphate 20-20-0;
(b) Mixed acid nitrophosphate with nitric and phosphoric acid 20-20-0;
(c) Ammonium phosphate nitrate 26-26-0;
(d) Urea ammonium phosphate 29-29-0.

FIGURE 10

SCHEMATIC FLOW SHEET FOR PROCESSES A, B, C, AND D

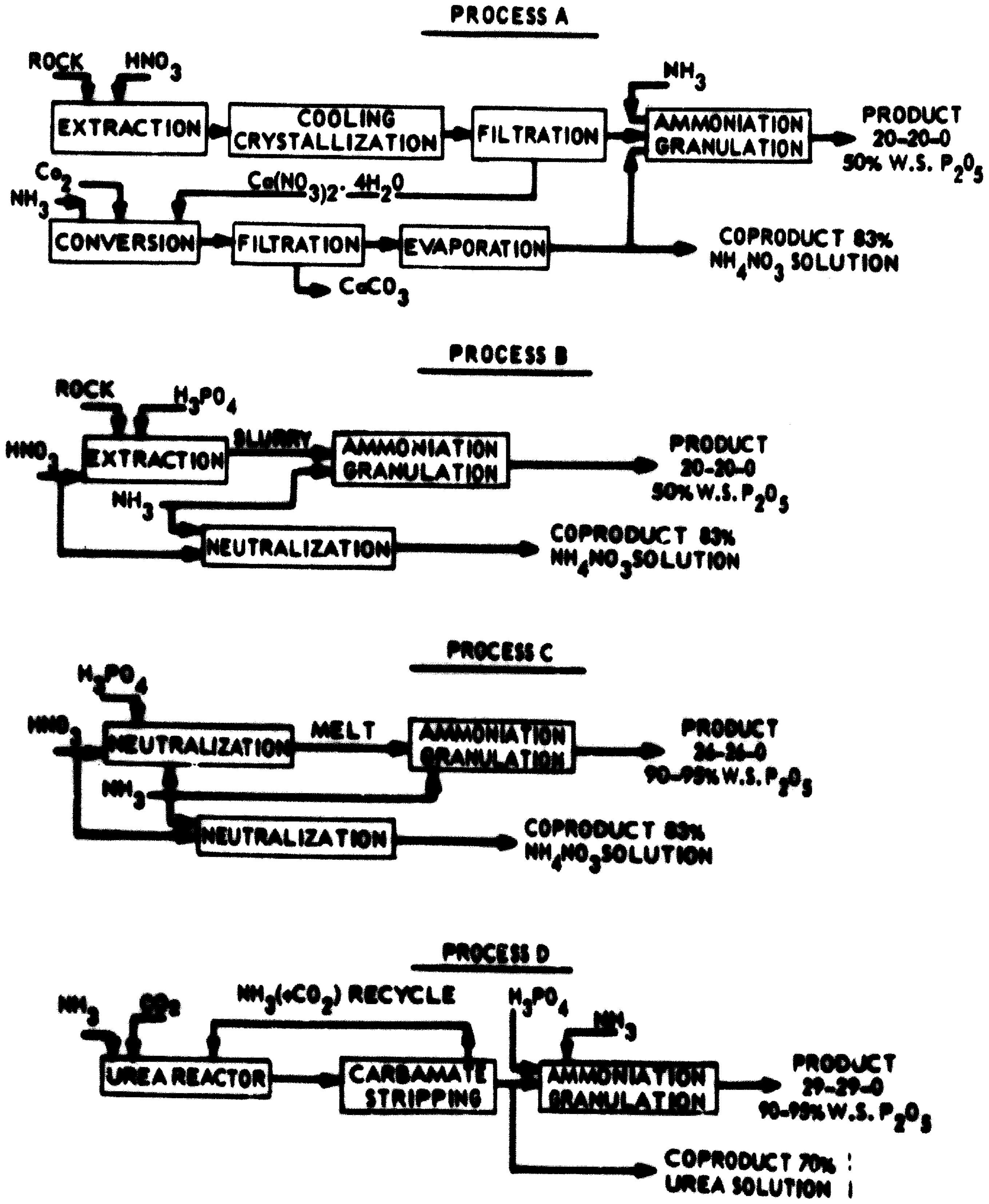


Table 10. Comparative economics of nitrophosphates, ammonium phosphate nitrate and urea-ammonium phosphate processes[a]

	A Nitrophosphate Odda process (20-20-0)		B Nitrophosphate HNO_3-H_3PO_4 process (20-20-0)		C Ammonium phosphate nitrate (26-26-0)		D Urea-ammonium phosphate (29-29-0)	
Plant capacity, metric tons/day	1130		1130		875		785	
Capital investment, million $	12,74		12,26		11.22		13,84	
	Cost, $/ton of							
	Product	$N+P_2O_5$	Product	$N+P_2O_5$	Product	$N+P_2O_5$	Product	$N+P_2O_5$
Raw materials[b]								
Ammonia ($39.62/ton)[c]	8,72	21.80	8.52	21.30	12.77	24.56	23.19	39.98
Nitric acid(100%) ($21.09/ton)[c]	15.45	38.63	14.67	36.68	15.16	29.15	-	-
Phosphoric acid (100% P_2O_5) ($117-119/ton of P_2O_5)[c,d]	-	-	16.06[e]	40.15[e]	31.55[e]	[illegible].67[e]	34.23[f]	59.01[f]
Phosphate rock (72% BPL, $14.77/ton)	9.60	24.00	3.31	8.28	-	-	-	-
Conditioner ($55.66/ton)	1.11	2.78	1.11	2,78	1.11	2.13	1.11	1.91
Less (1% of production cost)	0.46	1.15	0.53	1.33	0.75	1.44	0.76	1.31
Sub-total:	35.34	88.36	44.20	110.52	61.34	117.95	59.29	102.21
Operating costs[b]	10.73	26.83	9.68	24.20	11.65	22.40	16.86	29.07
Total production cost:	46.07	115.18	53.88	134.72	72.99	140.35	76.15	131.28
Return on investment (20% pretax)	6.80	17.00	6.56	16.40	7.74	14.88	10.75	18.53
Nitrogen solution credit ($141/ton of N)	-16.93	-42.32	-16.93	-42.32	-22.02	-42.34	-24.70	-42.53
Sales expense	9.80	24.50	9.80	24.50	11.55	22.21	12.24	21.10
Wholesale price, f.o.b., bulk, $/metric ton								
Product	45.74		53.31		70.26		74.44	
$N+P_2O_5$		114.36		133.30		135.10		128.33

---

a 227 metric tons per day each of nitrogen and P_2O_5 as 1:1:0 and 136 metric tons per day of nitrogen as solution.

b Includes production of nitrogen solutions

c Captive-use costs; includes return of investment.

d Sulphur at $36 per metric ton, delivered.

e 54% P_2O_5 acid.

f 40% P_2O_5 acid.

/...

Electric furnace phosphoric acid

84. Considering the high cost of sulphur and the world shortage, the production of electric-furnace acid in situations where low cost electricity is available has become important. Figure 11 shows the cost relation between furnace process and wet process acids. Tables 11, 12, 13 and 14 show capital costs and production costs of furnace process and wet process phosphoric acid at a hypothetical plant in Florida, United States of America. Similar cost data would apply to plants in Morocco, United Arab Republic or other countries having phosphate rock and low-cost electric power available.

FIGURE 11

COST RELATIONS BETWEEN FURNACE-PROCESS AND WET-PROCESS ACIDS (DOES NOT INCLUDE RETURN ON INVESTMENT)

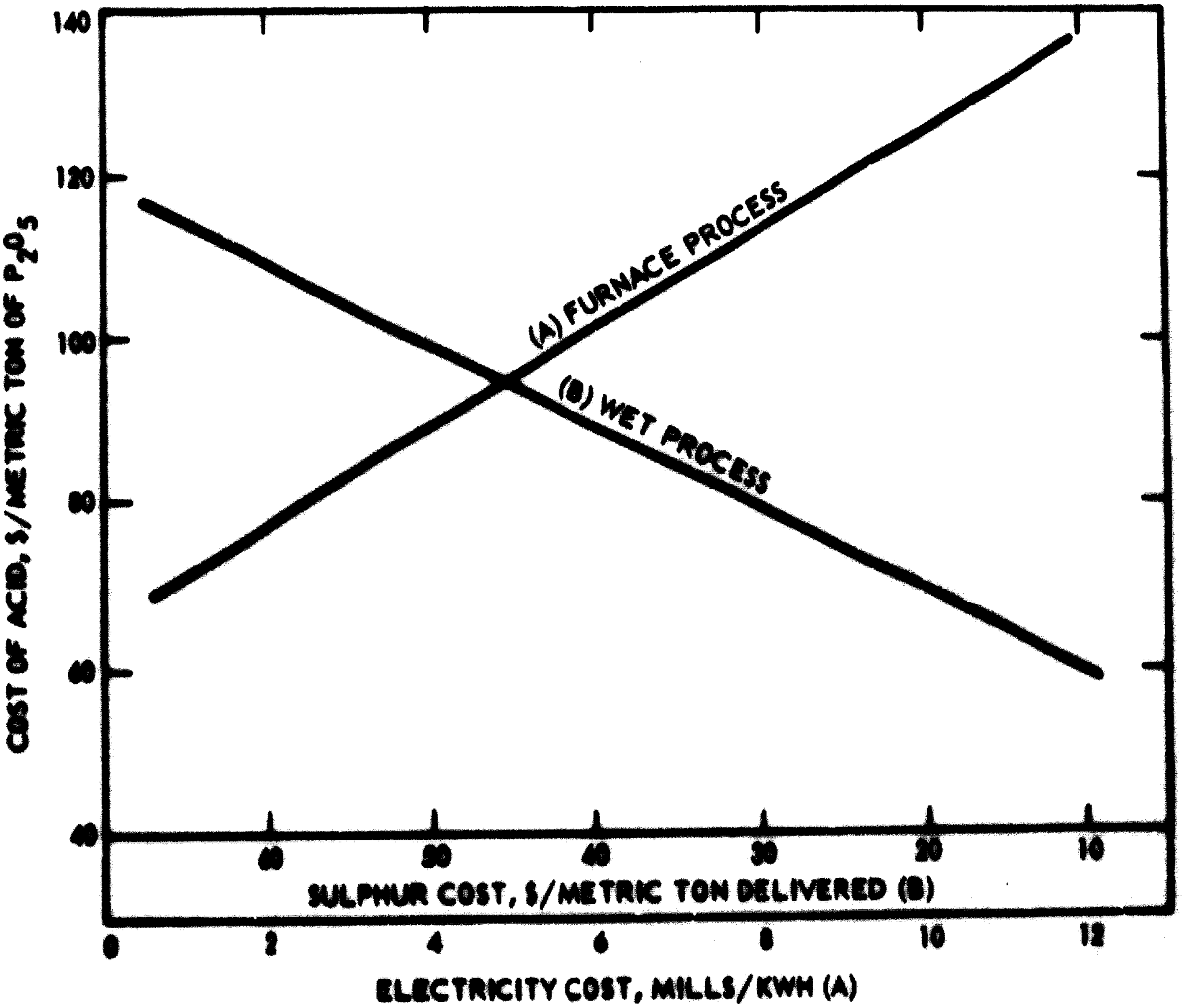


Table 11. Capital cost of wet-process acid plant

	Total	Rock grinding	Sulphuric acid	Phosphoric acid (31%)	Phosphoric acid (54%)
			(000 $)		
Battery-limits plants	9,429	1,410	3,494	2,705	1,820
Land					
Soil analysis	10	3	3	3	1
Plant area	50	17	17	14	2
Cooling pond	330			110	220
Gypsum disposal	117			117	
Dikes					
Cooling pond	293			98	195
Gypsum pond	200			200	
Site improvements					
Paving, fencing, lighting, telephone entry, and clearing	72	24	24	21	3
Railroad tracks and scales	144	108	35	1	
Cooling water					
Pumps and lines	202			63	139
Neutralization facilities	250			83	167
Pipe racks between plants	23		2	10	11
Steam piping	85			22	63
Offices and service buildings	754	188	189	188	189
Wells and piping	240	5	208	25	2
Power distribution	200	75	25	75	25
Mobile equipment	130	16	16	66	32
Sub-total:	12,529	1,846	4,013	3,801	2,869
Engineering	2,506	370	802	760	574
Sub-total:	15,035	2,216	4,815	4,561	3,443
Contractor's fee and overhead	1,504	222	482	456	344
Total investment:	16,539	2,438	5,297	5,017	3,787

/...

Table 12. Capital cost of furnace-process acid plant

	Total	Feed preparation	Phosphorus	Phosphoric acid
	(000 $)			
Battery-limits plants	22,260	5,000	14,260	3,000
Land				
Soil analysis	10	4	4	2
Plant area	50	20	20	10
Cooling ponds	30		18	12
Neutralization (waste) pond	10		6	4
Dikes				
Cooling ponds	65		33	32
Neutralization (waste) pond	26		13	13
Site improvements				
Paving, fencing, lighting, telephone entry, and clearing	75	29	29	17
Railroad tracks and scales	127	82		45
Raw materials storage	1,411	1,411		
Product storage and shipping	482		100	382
Cooling water				
Pumps and lines	110		60	50
Neutralization facilities	150		75	75
Pipe racks between plants	20		10	10
Steam, water, and acid piping	300	50	200	50
Offices and service buildings	527	210	210	107
Wells and piping	100	10	50	40
Power distribution	700	50	600	50
Mobile equipment	150	25	100	25
Sub-total:	26,603	6,891	15,788	3,924
Engineering	5,320	1,378	3,157	785
Sub-total:	31,923	8,269	18,945	4,709
Contractor's fee and overhead	3,192	827	1,894	471
Total investment:	35,115	9,096	20,839	5,180

/...

Table 13. Estimated production cost of wet-process acid

Plant capacity as acid: 544 metric tons of P_2O_5 per day (340 days/yr);
184,960 metric tons of P_2O_5 annually

	Delivered unit cost, $	Quantity per ton of P_2O_5	Cost, $/ton of P_2O_5
Sulphuric acid section			
Sulphur (2.85 tons of H_2SO_4)	38.50/metric ton	0.96	37.04
Electricity	0.006/kwh	29.8	0.18
Cooling water	0.00528/cu.m.	91.79	0.48
Boiler feed water	0.1057/cu.m.	4.17	0.44
Filtered water	0.0264/cu.m.	0.542	0.01
Salaries and wages	4.00/man-hr.*	0.176	0.70
Supplies			0.12
Maintenance, 6%/yr. of investment			1.72
Depreciation, $5,297,000, 15 yr			1.91
Sub-total:			42.60
Phosphoric acid section			
Phosphate rock	6.06/ton	3.58	21.69
Electricity	0.006/kwh	331	1.99
Water	0.00528/cu.m.	20.86	0.11
Salaries and water	4.00/man-hr.*	0.83	3.32
Laboratory analyses			0.26
Acid storage and distribution			1.32
Supplies and chemicals			1.76
Maintenance, 6%/yr of investment			3.65
Depreciation, $11,242,000, 15 yr			4.05
Sub-total:			38.15
Total (direct):			80.75
Overhead			4.96
Taxes and insurance (total, 2%/yr on $16,539,000 investment)			1.79
Total:			87.50

* Includes benefits.

/...

7. 10. 71

LIST OF FIGURES

I. GENERAL REVIEW

Role of fertilizer industry

1. The fertilizer industry is a branch of the chemical industry, but it is an atypical branch in that it has only one customer, namely, agriculture. The fertilizer industry is therefore a part of manufacturing industry and at the same time an integral part of agriculture.

2. Fertilizer is one of the five principal agricultural inputs necessary for increasing agricultural productivity: fertilizer, improved seed varieties, water, pesticides and farm machinery. All these inputs are necessary in order to raise agricultural yields, but fertilizer is probably the most important one in most cases. Some countries, such as the United States and Japan, have estimated that approximately one-half of the increases in agricultural yields attained may be attributed to greater use of fertilizer.

3. Because of its important role in increasing agricultural productivity, the fertilizer industry might be considered as the most urgently needed industry in many of the developing countries, particularly those with present or impending food shortages.

4. Although agriculture is its only major customer, the fertilizer industry has links with many other industries. The oil and natural gas industries supply hydrocarbon raw materials to the fertilizer industry. The mining industry supplies phosphate rock, potash minerals and sulphur. Ammonia produced by the fertilizer industry has many industrial applications. Ammonium nitrate is used as an industrial explosive, particularly in coal mining. Urea is used in making urea-formaldehyde plastics. Phosphoric acid has many industrial uses. Ammonium phosphate is used as a fireproofing chemical. Ammonium chloride is used in the manufacture of electric dry cells. Ammonium chloride and

/...

soda ash are made as joint products in a process which is used in several Asian countries. Lastly, the fertilizer industry is an important buyer of catalysts.

Trends in the world fertilizer industry

5. World production and consumption of chemical fertilizers have experienced tremendous growths throughout this century. This growth is illustrated by the following data on fertilizer consumption (in thousand metric tons of plant nutrient):

	Nitrogen (N)	Phosphates (P_2O_5)	Potash (K_2O)	Total
1905-1906	366	1,047	515	1,928
1913-1914	702	2,137	1,022	3,861
- - - - - - - - - - Decline during First World War - - - - - - - - - -				
1919-1920	757	1,729	1,070	3,556
1938-1939	2,670	3,637	2,904	9,211
- - - - - - - - - - Decline during Second World War - - - - - - - - - -				
1946-1947	2,568	4,368	2,677	9,613
1960-1961	10,200	9,845	8,465	28,510
1965-1966	17,390	14,525	12,120	44,035

6. These data exclude mainland China, North Korea and North Viet-Nam. They refer to consumption, but production would be about the same, except for losses and changes in stocks. They do not include organic materials, except organic materials processed in factories and incorporated in commercial fertilizers. Organic materials were a substantial part of the totals in the early years of the century, but today they are only a small fraction of 1 per cent of total commercial fertilizers.

/...

7. Table 1 and figure 1 give detailed data on world consumption of fertilizers from 1930-1931 to 1965-1966. Also shown are some projections for 1970-1971 and 1975-1976, which will be discussed later in this paper. Again, production may be equated approximately to consumption. The growing importance of nitrogen is clear from figure 1, where nitrogen is shown to have been the lowest of the three nutrients as recently as 1954-1955, whereas in 1965-1966 it was clearly forging far ahead of phosphorus and potash. The projections in figure 1 indicate that this trend will probably continue.

8. The growth of production and consumption of fertilizers has been much more rapid since the Second World War than it was between 1919 and 1939, and the rate of growth of nitrogen and phosphorus has been even higher during the past five years. These facts are summarized in the following percentages:

	N	P_2O_5	K_2O	Total
Average annual rate of growth 1919-1920 to 1938-1939 (19 years)	6.9	4.0	5.4	5.1
Average annual rate of growth 1946-1947 to 1965-1966 (19 years)	10.6	6.5	8.3	8.4
Average annual rate of growth 1960-1961 to 1965-1966 (5 years)	11.3	8.1	7.5	9.1

9. Advance estimates for 1966-1967 indicate that the high growth rate of 1960-1961 to 1965-1966 is continuing. It remains to be seen whether this high rate of growth will continue for the next five or ten years; however, in view of the large-scale construction of new fertilizer plants around the world, it seems very likely that a high rate of growth will continue for the next few years at least.

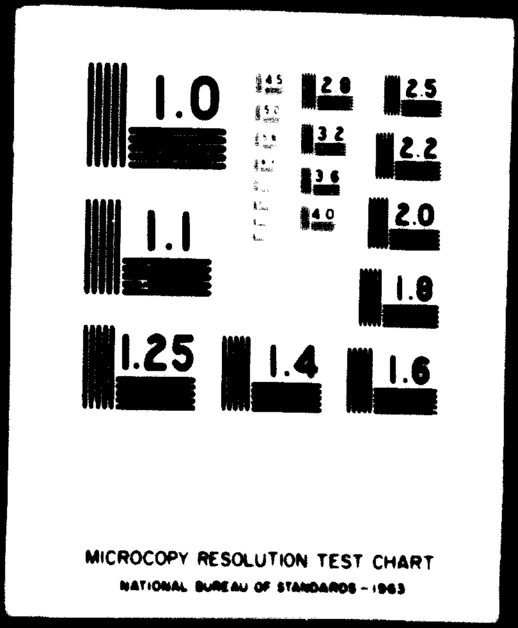
10. Table 3 compares the growth rates of fertilizer production and consumption in the developed and developing areas. The developing areas are increasing production of all nutrients much more rapidly than are the developed

/...

2 OF 2

DO

1888


1.0
4.5
5.0
5.6
6.3
7.1
8.0
2.8
3.2
3.6
4.0
2.5
2.2
2.0
1.1
1.8
1.25
1.4
1.6
MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS - 1963

parts, or services of foreign technologists may be responsible for many of the poor operating records. Complicated, time-consuming procedures for obtaining approval for importation may be as damaging as outright prohibition. Heavy taxes on imports may be a handicap.

106. The effect of these numerous causes of poor production is to limit the amount of fertilizer made available to the farmer and to increase the cost of the fertilizer that is produced. The economic success of modern fertilizer plant operation usually depends on sustained operation at or near capacity. Each plant has a "break-even" operating rate, below which the operation is uneconomical. The break-even rate may vary considerably from one plant to another, but 70 per cent may be a typical value. A country which has a good record in making full use of the facilities it has will inspire confidence in investors in new plants if they are needed. Conversely, where previous financial aid or investment has been poorly utilized, there is little reason to suppose that more capital will help.

107. Not all countries should expect to establish a full-fledged fertilizer industry. Many countries are too small either in total area or in agricultural potential to furnish a market for an economically sized fertilizer plant. In such cases, regional planning can be helpful. For instance, if one country has low-cost natural gas, it could produce ammonia for itself and other countries of the region. Another country may have phosphate rock, a third may have sulphur or low-cost electric power, and a fourth may have potash. Careful planning is needed to determine where production facilities should be located and what products or raw materials should be shipped.

108. The advantages of regional planning and co-operation are not limited to small countries. Adjacent portions of large countries may benefit also. For instance, the north-western part of the United States and the south-western part of Canada constitute a region in which phosphate rock, potash and finished fertilizers move freely across the border with substantial advantages to both countries.

/...

IV. POTASH

Known potash ore deposits

109. In about 1843, a brine well in Germany was found to contain potassium salts, and shortly thereafter German scientists established the fact that potassium was an important plant nutrient. However, potash was not used as a commercial fertilizer ingredient in major quantities until early in the twentieth century. Its primary use in the early period of the industry was in dyeing, tanning, glass, fireworks, explosives, soap and other similar chemical industries.

110. Germany controlled world production of potash from approximately 1860 until the early 1930's, when demand stimulated the development of the Carlsbad, New Mexico, deposit. Production capability increased in the Carlsbad district to meet demand during the Second World War, and the increased demand in the post-war period. World demand has increased rapidly since the middle 1940's at a rate of 8 per cent per annum. The potash deposit in Carlsbad, New Mexico, was discovered in 1925, but mining was not started there until 1931.

111. The recent expanding demand for potash in the world market has stimulated the development of the Saskatchewan, Canada, deposits. At the present time, three companies there are producing potash and five other companies are developing properties. There are also several other major companies making feasibility studies of the properties they control.

112. There are over 140 operations in the world where potash is being recovered. This includes both brine and mining operations. Currently, fourteen properties are under development. At the present time, over 95 per cent of the world's production of potash is used as fertilizer.

Exploration

113. With few exceptions, the major potash deposits in the world have been found as a result of oil drilling operations. The deposits in New Mexico and Saskatchewan are typical examples. The first report of potash in Saskatchewan

/...

was made during the Second World War, when a wildcat oil well intersected a major salt horizon and some potash salts were identified in the remnants of the leached core. Development of the Saskatchewan deposits began in 1951 and exploration drilling for potash started near Saskatoon, Saskatchewan. More recently, oil exploration work in Brazil and West Africa has indicated the presence of potash in a salt horizon; development by shaft sinking and further drilling is now in progress.

114. Potash is derived principally from two sources: first, underground deposits of bedded potash; and, secondly, to a less extent, from surface brines. The major production at the present time is from bedded deposits, which are interbedded with halite or common salt. Some of the ores are mined solely for KCl, while others are mined for potassium sulphate and mixtures of the two minerals.

115. Exploration for potash deposits is unlike exploration for most non-metallics in that potash deposits do not normally outcrop at the surface. Potash exploration is also unlike exploration for metallic deposits in so far as most geophysical methods are not applicable to the location of potash. Gravity surveys are of some use in locating potential exploration areas because salt masses are generally of a lower density than the surrounding rock. The presence and mineralogical iden tity of underground potash can be demonstrated only by taking core samples. Drill ing, therefore, generally begins earlier in potash exploration programme than it would for other mineral commodities. The cost of drilling may also exceed that for other mineral commodities in so far as special techniques are required to preserve the soluble salts recovered from the core. It is also generally necessary to take a larger diameter core to sample potash deposits than is needed for other mineral commodities because, in many cases, the potassium salts are coarse and crystalline. It is apparent, therefore, that exploration for potash deposits requires a different approach from that used for the exploration of most mineral deposits.

/...

Physical characteristics

116. It is difficult for mineral properties containing kainite ($KCl.MgSO_4.2.75H_2O$) and carnallite ($KCl.MgCl_2 6H_2O$) ores to compete in the world market with mines which produce sylvite or KCl. The sylvite deposits in Canada have only minor metallurgical problems; however, the mining horizon is over 3,000 feet below the surface and at this depth the evaporites (salt horizon) which contain sylvite, carnallite, and sodium chloride are plastic. Conventional mining much below this depth is not economically feasible, because of the plasticity of the deposit. The sylvite deposits in New Mexico are more complex, in many cases containing a mixture of many potash salts. The only major operating kainite deposits in the world are in Sicily, where there are substantial reserves with average K_2O content of about 12 per cent. The processing is fairly complicated and potassium sulphate is the usual end result. Little or no potassium chloride is produced from these deposits.

117. In some of the major potash deposits, the horizon to be mined is extremely thin and special mining equipment and methods must be used to extract the ore. The depth at which potash deposits are mined varies from a few hundred feet below the surface to as much as 5,000 feet by solution mining techniques. No underground workings are envisaged below 3,700 or 3,800 feet at the present time. In the United States, the potash deposits in New Mexico are from 500 to 2,500 feet below the surface. The deposit being worked in Utah is about 2,700 feet below the surface. In Canada, there are in effect two potash horizons, the upper bed being the important source for the mine in western Saskatchewan. The producing mines and those that are now being developed will be operating at depths of from 3,000 to 3,700 feet depending upon location in the province. Those in the western part will be the deeper mines.

118. In France, potash deposits are from 1,500 to 3,700 feet below the surface. There are two separate beds, the upper bed being thinner and richer and the lower bed, although thicker, of a lower grade. Potash is currently being mined in Germany from 3,000 to 3,800 feet. In Spain, the depth varies from 900 to 1,600 feet

/...

119. In the Soviet Union, the deposits in east Galicia are from 300 to 2,000 feet. The Starobin deposits are from 1,200 to 3,000 feet deep and the Caspian deposits are reported to be 900 to 2,000 feet. The important mines in Upper Kama are being worked at depths of from 1,000 to 3,700 feet. The kainite deposits in Sicily are from 900 to 1,500 feet below the surface. Two horizons are known to occur in the Congo (Brazzaville) deposit, one approximately 1,000 and the other about 1,400 feet below the surface. The potash deposit in Yorkshire, England, is reported to be from 4,000 to 5,000 feet below the surface.

120. Saline deposits are composed of interbedded halite (NaCl), clays, gypsum and anhydrite. Occasionally the halite beds contain concentrations of potassium minerals which may be economic.

121. One other source of potash is natural brine such as sea water or as found in contained areas such as the Dead Sea. At the present time, the only major production from this type of source is the evaporating operation in the western portion of the Dead Sea being performed by an Israeli company. Minor amounts of potassium are produced from the nitrate fields in Chile. The product is potassium nitrate, a by-product of the sodium nitrate industry.

122. In connexion with the mining or extraction of potash from salts from the sources listed above, several problems are inherent in the particular deposit. Production of potash from the Dead Sea, for example, is limited by the dike areas; construction and maintenance of these dikes is an important factor in operating costs. Several other brine sources have been considered, and feasibility studies have been and are being made to see if it is possible to produce potash salts from these brines economically.

123. The possibility of producing potassium salts from the Great Salt Lake in Utah is one of the projects now being studied by several major chemical companies; the outcome of these studies is still unknown. The brine deposits in north-central Libya have been investigated, but to date no major effort has been made by any company to develop this possible minor source of potash. A pilot plant is being operated in the Sechura desert brine fields in northern Peru to ascertain the possibility of recovering potassium salts and other known elements of economic value.

/...

Potash mining

124. There are three basic methods of extracting potash from underground deposits.

125. The first is the so-called conventional mining method, whereby ore is drilled and blasted, loaded by mechanical loaders, conveyed by cars or trucks to a conveyor belt and then transported to the shaft, where it is hoisted to the surface plant.

126. In the second method, mining machines are used to break the ore at the mine face. These machines—either the ripper or the boring variety— replace the blasting and loading operations. The ore is conveyed through the machine to a conveyor belt and thence to the mine shaft and hoisted. Machine mining is a new development, used commercially for only the last five years. This is the method now in use in Saskatchewan mining of the flat-lying potash deposit.

127. The third method is also comparatively new from a commercial standpoint. It is the solution mining method, being used in only one operation in Saskatchewan. In that location, the potash deposit is more than 5,000 feet below the surface. Owing to this great depth, underground mining methods were not considered. In solution mining, a hot water solution is pumped down into the potash horizon and recovered through auxiliary wells. The potash salts contained in the returned solution are then treated in crystallizers and the potassium salts extracted. The main disadvantage of this solution mining method is its lack of selectivity. All soluble salts are dissolved in the horizon being worked.

128. The possibility of developing another deposit for solution mining is now being investigated. This deposit is near Whitby, Yorkshire, in north-east England. The potash occurs at a depth of about 4,000 feet and there is an overlying stratum of about 1,000 feet which is a strong aquifer. This overlying aquifer and the depth have discouraged the development of this deposit by conventional underground mining methods.

129. Mining by conventional drilling and blasting methods or with continuous miners is difficult in faulted and steeply dipping deposits such as those found in certain parts of Germany. Where the distortion has been extreme, other mining

/...

methods have had to be used. Some deposits in Germany have been so distorted by movement that the beds are essentially vertical. These deposits are being mined by extracting a certain vertical interval and then refilling the mined-out area with salt to support the walls of the deposit.

130. A newly developed mine in North America is in the process of developing equipment and methods to extract potash from a steeply dipping and rolling bed. Wherever potash is found in beds which are not hearly horizontal, the cost of mining will be much higher than flat-lying deposits owing to the lack of mechanical equipment designed to operate under those unusual conditions. A not uncommon hazard encountered in the underground potash mines is the presence of brine, gas and even oil in the ore or in the adjacent horizons.

Processing methods

131. The physical and chemical characteristics of the deposit dictate the processing methods used to recover the potassium salts. In some areas, the physical mixture of anhydrite with the potassium salt in micron sizes makes it very difficult to produce a coarse product containing 60 per cent K_2O. To achieve the coarser sizes it is sometimes necessary to compact and resize the potassium salt concentrate. The mining and processing cost is increased where mixed salts occur. An example would be kainite mixed with sylvite. The presence of keiserite and polyhalite is also extremely detrimental to the recovery of a saleable product. High sodium-ion content is detrimental in potassium salts which are to be used in saline soils. Potassium chloride is not acceptable as a source of potassium when the soil is high in sodium chloride. The additional chloride in the soils makes them unproductive after sustained usage.

132. Currently, three natural brine deposits are being worked for potash. The Searles Lake deposit in California is producing potassium chloride as a by-product. Potassium sulphate is also produced from that deposit. The Wendover deposit in Utah is producing potassium chloride and the Dead Sea near Sodom, Israel, is also producing potassium chloride. Three other plants are in the planning stage—one each in the Soviet Union, Jordan, and the Great Salt Lake in Utah. The potassium

/...

chloride content of the Dead Sea brines is about 1 per cent and may reach 1.6 per cent. The Bonneville brines near Wendover contain 0.08 - 1.2 per cent KCl. There is considerable difficulty with the Searles Lake brine because it forms a complex salt having a composition of $Na_2SO_4 \cdot 3K_2SO_4$ or $K_3Na(SO_4)_2$. The Great Salt Lake is reported to contain 0.92 per cent KCl. Sea water normally contains about 0.05 per cent K_2O. Slimes consisting of insoluble material present a very serious problem in the brine operations as extra filtration apparatus must be incorporated in the circuit.

133. The processing problems in New Mexico are more complex than those found in the Canadian deposit, but the mining conditions at 800 - 1,000 feet are considerably better than those in Canada. The complex ores found in Germany and France pose two kinds of problems.

134. The depth in some areas is excessive and temperatures are high. The metallurgy is costly as these ores contain high percentages of carnallite. Carnallite reacts unfavourably in deep deposits because of its water content, and it is extremely hugroscopic. It does not have the physical strength characteristics of sylvite or langbeinite. The deposits in Spain, while not deep, are folded and distorted, creating some mining problems. The processing in Spain is complicated by the presence of carnallite in some of their deposits and brine in others.

/...

World supply/demand situation

135. Eight factors point to increasing use of fertilizers in the world, and all these will have an effect on the future consumption of potash. Those factors are as follows:

(a) The fact that, in the next fifteen years, there will be 1.5 thousand million more people in the world to feed;

(b) An increasing standard of living in developed and developing countries, which means more meat consumption and consequently more grain consumption to produce the meat;

(c) More intensive agriculture and higher technology, which means more fertilizers;

(d) Increasing profit to farmers from their investment in fertilizer;

(e) Higher world government priorities on agriculture to grow more food;

(f) Increasing agricultural education, with growing awareness of what can be achieved with fertiliser;

(g) Declining cost of fertiliser relative to machinery, land and labour;

(h) Acceleration of soil depletion rates, with the day ever closer when man must stop taking more nutrients out of the soil than he is putting in.

136. Currently, world potash production capacity is divided approximately as follows:

United States and Canada	29 per cent
USSR and eastern Europe	30 per cent
Other developed nations	38 per cent
Developing nations	3 per cent

As to the world-wide demand, potash consumption in 1965-1966 was about 14.4 million tons, up 8 per cent from the previous year. 1966 - 1967 capacity is placed at about 16.5 million tons and demand at 15.7. For 1969-1970, capacity is estimated at 22 million and demand at 19 million. After 1970, an average annual growth rate in demand of about 6.3 per cent is expected up to and including 1980.

/...

Development of a potash complex

137. Manufacturing costs of potash are directly related to grade, depth and capacity. If we consider, as part of manufacturing costs, those elements of costs which must be borne by the producer in developing countries, then manufacturing costs are also directly related to investments in distributing facilities (railroads, roads, port facilities), investment in housing, schools and hospitals, and investments in basic utilities (water, power, fuel).

138. Mining costs per ton of finished product are sensitive to the ore content of the ore body. Obviously a high-grade ore containing little waste (salt) is much more productive per ton mined than one of low grade. For example, in Canada (Saskatchewan), the ore grade of the ore body runs 26 - 28 per cent K_2O: whereas some of the low-grade Carlsbad mines are mining ore of 12-14 per cent K_2O. For a given tonnage, this means that a Canadian producer needs to mine less than one-half of the ore mined by a Carlsbad producer.

139. Refinery costs are also sensitive to grade, although not nearly as much as mining costs, since the separation and disposal of waste occurs early in the circuit and, from that point forth, costs are similar regardless of grade. Costs are directly related to recoveries and high-grade ore always results in higher refinery recoveries than low-grade ore.

140. Costs rise as depth increases. This is due to three factors. First, a deeper shaft is a more costly investment, hoisting costs are proportional to distance lifted, and underground recovery (amount of ore removed per unit of advancement)is inversely proportional to depth; therefore, as underground recovery goes down, costs go up. Shaft costs are also affected by the geological formations through which it is sunk. Depth alone is not the only cost influence.

Table 14. Estimated production cost of furnace-process acid

Plant capacity as acid: 544 metric tons of P_2O_5 per day (340 days/yr);
184,960 metric tons of P_2O_5 annually

	Delivered unit cost, $	Quantity per ton of P_2O_5	Cost, $/ton of P_2O_5
Raw materials section			
Rock	6.06/ton	2.25	13.64
Matrix	1.10/ton	2.62	2.88
Coke	18.74/ton	0.588	11.02
Electricity	0.003/kwh	71.7	0.22
Water	0.00528/cu.m.	20.86	0.11
Salaries and wages	4.00/man-hr*	0.22	0.88
Mobile equipment			0.28
Supplies			0.06
Maintenance			1.33
Depreciation, $9,096,000, 15 yr			3.24
Sub-total:			33.66
Furnace section			
Electricity	0.003/kwh	57,623	17.28
Carbon electrodes	0.309/kg.	6.50	2.01
Water	0.00528/cu.m.	25.03	0.13
Steam	1.10/ton	1.00	1.10
Salaries and wages	4.00/man-hr*	1.15	4.60
Air	0.71/M cu.m.	0.078	0.05
Ammonia			0.07
Laboratory analyses			0.41
Mobile equipment			0.11
Supplies			0.54
Maintenance			5.53
Depreciation, $20,839,000, 15 yr			7.50
Sub-total:			39.33
Acid section			
Electricity	0.003/kwh	44	0.13
Water	0.00528/cu.m.	83.44	0.44
Air	0.71/M cu.m.	0.041	0.03
Salaries and wages	4.00/man-hr*	0.18	0.72
Equipment operation			0.02
Acid storage and distribution			1.32
Supplies			0.07
Maintenance			1.10
Depreciation, $5,180,000, 15 yr			1.86
Sub-total:			5.69
Total (direct):			78.68
Overhead			7.17
Taxes and insurance (total, 2%/yr on $35,115,000 investment)			3.79
Credit for sale of byproducts			-5.51
Total:			84.13

* Includes benefits.

In Canada, a shaft is over 3,100 feet deep and costs (fully equipped) approximately $10 million. This is a ratio of about 6½ to 1 in comparison with Carlsbad costs and reflects not only the depth, but the treacherous geological formations passed through in reaching the Canadian ore body.

141. Potash producers are no different from other large bulk producers. Volume has a direct influence on costs. A high capacity operation invariably has lower unit costs than a low capacity plant. This is particularly true of operations with high fixed investment and operating costs. For instance, in Canada, a conventional mining operation will have invested $20 million in shafts alone. If to this is added underground equipment, a refinery, office and laboratories all built to withstand the severe Canadian winters, a producer will have over $50 per annual ton invested. In the refinery, manpower is needed to attend to certain controls regardless of the volume processed. Thus, production unit costs are inversely proportional to capacity.

142. In developing countries, where labour is readily available at a very low cost, a producer will find it more advantageous to hire many men rather than invest in complicated equipment which is challenging to operate and may exceed the capabilities of the local labour force. In this case, unit costs will not change significantly with volume.

143. Preparing for the development and operation of a potash complex is at best a tremendous undertaking, requiring engineering studies, core drilling, ore testing, economic evaluation and heavy capital investments, all within the framework of certain element of risk. In developing countries, the complications are multiplied and aggravated by lack of industrialization, transportation, capable work force, sufficient utilities, housing, foreign exchange and sometimes rigid governmental restrictions and regulations.

144. Unfortunatly, most of the major producing deposits of the world are 200 to 1,000 miles from the ocean, and are serviced by complex transportation systems.

/...

145. Construction costs at the world's potash mines may vary from $30 per ton of annual capacity to as much as $60 to $70 per ton. Moreover, construction costs have been escalating at 5 to 6 per cent per annum over the last five years, with similar increases probably to be expected in the future.

146. Development of potash deposits from discovery to actual production has in some instances, taken several decades owing to supply and demand conditions. Actual construction of mine and plant facilities has taken from three to six years, depending upon the particular deposit to be developed. To be economically feasible, a potash operation should have adequate reserves to sustain operations for twenty-five to fifty years, and must be a fairly high tonnage producer. This in turn demands an adequate power supply to operate the underground equipment, refinery pumps, motors and other equipment; an adequate water supply for plant processing, brine make-up, dissolving and flotation; a source of natural gas or fuel oil for power plant, steam and drying; a reliable supplier of repair parts and supplies or the equivalent in plant inventory; and a labour force.

147. In developing countries, the labour available is unskilled and inexperienced, which means that extensive training programmes have to be undertaken. Even though Canada is an advanced country, the rural location of some of the potash mines has also involved highly organized training programmes to train farmers to operate mining and refining equipment.

148. An example of the difficulties may be seen in Ethiopia, which has within its borders a very large deposit of potash. Some day this will undoubtedly be commercially exploited. Early investigations of feasibility were not attractive enough to cause any producers to enter production; there is some exploratory work now in progress, and an American group is engaged in a comprehensive feasibility study.

149. Among the factors which discouraged early investigators were:

(a) Remote location - requiring extensive development of roads, port and energy sources;

(b) Climatic conditions - severe surface temperatures in excess of 130°F make operations difficult and expensive;

(c) Lack of water - a considerable quantity of water is required for processing potash to modern standards of quality;

(d) Lack of skilled labour - personnel must be imported and housing facilities must be built;

(e) Ore quality - although of high potash content, it contains impurities which make processing difficult, complex and expensive;

(f) Government - run by leaders experienced but advancing in years; therefore, the future of governmental attitudes is uncertain.

150. In evaluating the Ethiopia project, geologists and mine engineers tested water sources, mining conditions, native customs and religious differences, site locations, port requirements, transportation facilities, living conditions, equipment availability and other factors. The economies were prepared, governmental and tax considerations determined, and capital requirements established. Some day this deposit will be commercially developed. There is a natural market for this raw material, which is large enough to support such development in spite of high operating costs.

Distribution

151. The transportation of bulk products has received increasing consideration during the last five years. It is necessary to know the physical distribution economies available in order to understand the market. Companies entering bulk markets, such as phosphate rock, potash, sulphur and others, will find that considerable resources and efforts have been expended to develop the lowest possible distribution costs.

152. Success within national borders depends on the proper use of existing movement facilities, and technological innovation is the most important in distribution. Geography is no longer a critical factor where large volumes exist, if the "total movement concept" is employed. This concept refers to the development of a distribution programme which exploits every opportunity from the time the product leaves the end of the production line to the time it reaches the ultimate user. Attention must be directed to the establishment of the cheapest and most efficient method of transportation to the port of export. Facilities at port must be adequate to load product aboard properly sized vessels at a speed which will ensure the lowest loading costs consistent with ship requirements. Vessel selection, through negotiation or construction, should always reflect the specific requirements of the product and the customer involved.

153. The port facility at destination must also be carefully considered. Often the economically sized ship cannot be used owing to severe restrictions at the port of entry as a result of draught limitations, inadequate handling facilities, lack of storage, inability to provide sufficient transportation equipment for the inland haul, or labour difficulties. It is no longer possible in world markets to depend on placing the burden of delivery on the final customer, unless he is willing and able to provide distribution facilities of his own. Utilisation of all distribution opportunities, as listed below, can preserve, or develop, world trade.

Movement to the port of export

154. Production plans must be geared to customer consumption, both domestic and export.

155. Strict control must prevail. Whatever proves to be the most economical and efficient delivery method whether rail, barge, motor truck or pipeline - any minor error could prove very costly.

156. Attention must be directed to the marshalling of the tonnage at port if storage is not provided. Any delay of the ships involved is costly.

157. If possible, control should be exerted over the port facility to ensure quick turnover of the vessel. Many suppliers have developed their own terminal complexes in order to avoid delays at publicly owned ports.

Ocean movement to port of import

158. The most specialized vessel should be selected. Obviously, huge ocean vessels create lower per ton costs than smaller ships for actual movement, but they may also create problems and costs that could not only destroy their hauling advantage but actually yield higher total distribution costs. Table 15 illustrates the operating cost comparisons of different sized ships based on experience. These costs include operating, management, fuel at sea, capital expense, repairs, maintenance and surveys of vessel.

Table 15. Operating costs of ships

Deadweight of vessel	Cost per day (in $)	Cost per deadweight ton per month (in $)
10,000	1,582	4.83
15,000	1,736	3.53
20,000	2,170	3.31
25,000	2,576	3.14
30,000	2,744	2.79
40,000	3,262	2.49

159. A cautionary note should be added: overspecialization of the vessel can result in a loss of pliability by eliminating the possibility of backhaul arrangements. A ship should be secured, or built, on the basis of customer requirements, but not to the extent as to destroy flexibility. Although many long-term contracts are predicted on an empty ballast movement from destination to the loading port, efforts to work with other industrial concerns should be pursued in order to curtail backhaul costs.

/...

160. Several years ago, it was difficult to secure return movements on bulk vessels. This is no longer true. Shipments of dry solids have increased from about 300 million tons in 1950 to over 700 million tons in 1965. In recent years, many ship owners have pooled their resources to form substantial bulk carrier groups in order to take advantage of this high volume.

161. The vessel should proceed to the discharge port at the swiftest and most economical speed. Through voyage data analysis, computers can contribute and in some cases are contributing to running ships in the most economical fashion.

Discharging port and movement to final destination

162. Although there are obvious advantages to large bulk carriers, the benefits can vanish unless discharging facilities are modernised. In many developing countries which purchase major amounts of bulk commodities, inefficient handling and shallow draughts prevent them from enjoying the low costs available under the total movement concept. Table 16 compares discharging costs in terms of ship time in port expressed in dollars per long ton.

Table 16. Discharge rate per running day
(per ton in US$)

Deadweight of vessel	1,000 LT	2,000 LT	3,000 LT	4,000 LT	5,000 LT
10,000	1.43	1.17	0.91	0.65	0.39
15,000	1.64	1.33	1.03	0.72	0.42
20,000	1.84	1.49	1.14	0.79	0.44
25,000	2.08	1.68	1.28	0.88	0.48
30,000	2.31	1.86	1.41	0.97	0.52
40,000	2.76	2.24	1.71	1.19	0.66

These discharge costs show the urgent need for modernisation of port receiving facilities. Without improvement, vessel specialisation is useless and a key area for distribution economies is destroyed.

/...

163. On key accounts, it is also advisable to investigate the movement from discharging port to final destination. Reductions in costs are often available if everyone involved is aware of the business available should distribution economies be maximized.

164. The successful potash producer must weigh and control every item of distribution expense. The competition that exists in world trade demands such efficiency.

Conclusions with respect to the developing countries

165. For the developing country wishing either to establish its own fertiliser industry or to increase its food productivity through greater agricultural yields, potash is essential. Most of the developing nations have no potash deposits within their borders, and for them there is no alternative but to import potash. The only decision facing them concerns the source from which potash should be obtained. Nations possessing potash deposits have to decide whether it is more practical to develop those reserves or to continue to import.

166. A number of considerations will enter into their decision. A basic consideration is the amount of foreign exchange available in the country, and its best use as far as food production is concerned. The approach here must be a strictly economic one based on established priorities. For example, if the world market price of potash is $40 per ton, the decision might be to import it as the most economical way to develop a fertiliser manufacturing industry. If potash were $50 per ton, on the other hand, the country might well decide that it should exploit its own reserves. There are certainly other national considerations which should be taken into account.

167. In the development of these potash reserves, most nations will find that they have to attract outside capital and manpower, and here they must ask themselves if the physical resources and the economic environment are attractive. The investor will, of course, tend to go where the return

/...

is largest and safest. In some developing countries, development under the public sector, based on needs, will seem necessary. For example, a company wishing to assist in the development of a potash project may have fifteen men and $50 million available. The company has its own set of priorities, and there are many alternate uses for the men and for the money. They will be sent where returns appear greatest relative to risk.

168. The investor, as well as the governing body of the country with the potash reserves, must also consider the competition the potash will meet. If the reserve is explcited, will it move to a market within a country, within a region, or will it have to compete against other world sources for the nearest natural market? Is the country part of a regional economic grouping? The group's schedule of tariffs, the needs of its members for potash, and the likelihood of reduced trade barriers in the future must all be taken into account.

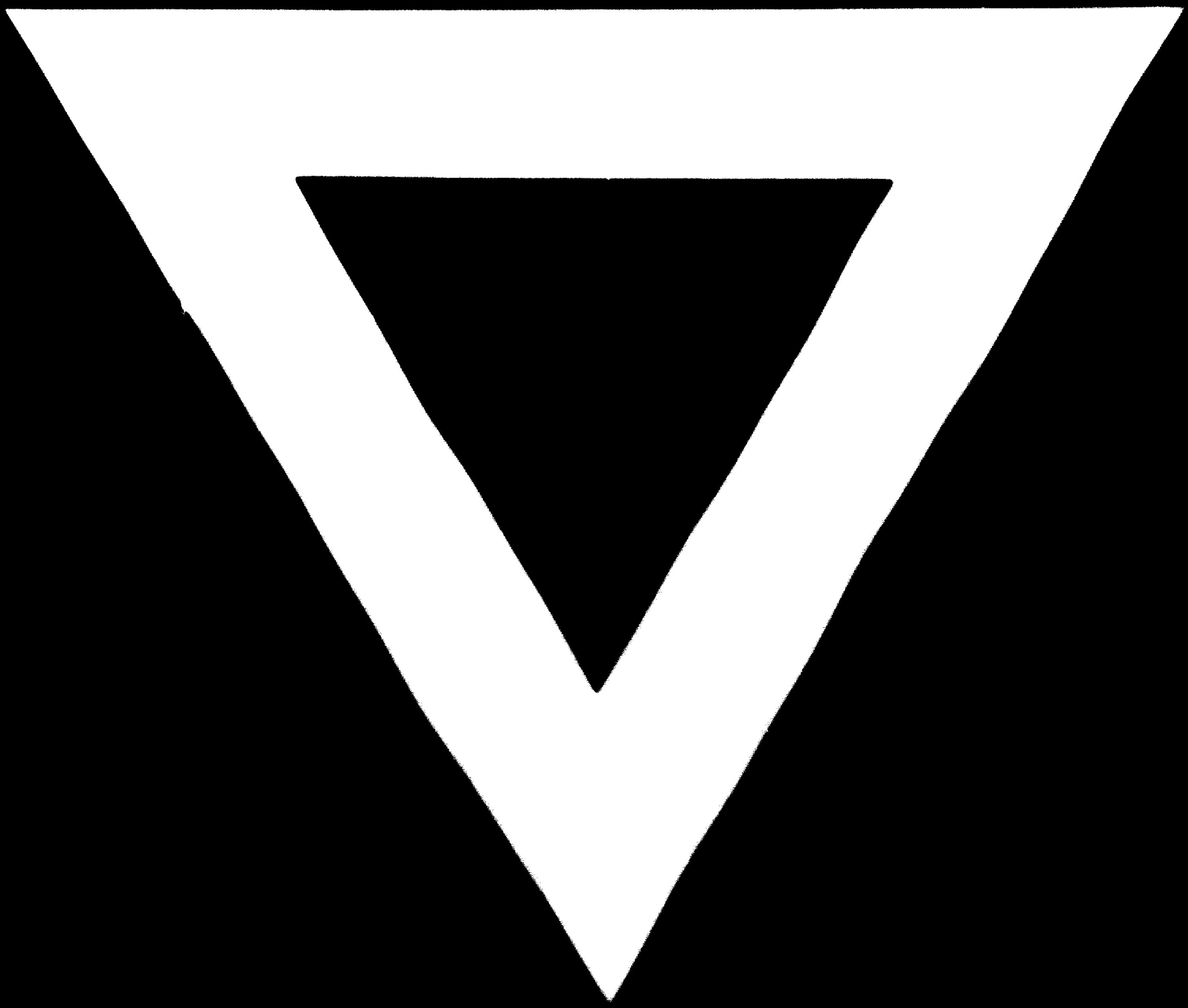
169. Four factors have to be studied before the developing nations take up potash exploitation.

(a) Most nations have no economically competitive deposits known so far. Potash is less available than phosphate, which in turn is less available than hydrocarbons needed in the production of nitrogen, the third major plant nutrient. Geographical survey and exploration have to be done extensovely.

(b) Early development costs of a potash mining project are higher than for the other two plant nutrients.

(c) The cost per unit of K_2O is the least per unit of the three primary nutrients, and therefore its purchase is least depressing to a nation's balance of payments.

(d) Potash and phosphate are used in soils only after nitrogen has been applied. Therefore, nations have traditionally developed their nitrogen first.



7. 10. 71

Shipment of phosphorus

85. A major advantage of the electric-furnace process is the high concentration of the intermediate product, elemental phosphorus. Phosphorus is readily shipped in mild steel tank cars, and water shipment by river barges or overseas vessels is feasible. Shipment of 1 ton of elemental phosphorus would supply the same amount of P_2O_5 as about 7.5 tons of phosphate rock plus 2.2 tons of sulphur for use in the wet process. One ton of elemental phosphorus is equivalent to the phosphorus content of 5 tons of triple superphosphate or diammonium phosphate derived from wet-process acid. Thus, when the market area is distant from the phosphate mine, a substantial saving in transportation cost can be made by shipping elemental phosphorus to the market area for conversion to fertilizer.

86. While the present estimate assumes that all of the elemental phosphorus is converted to phosphoric acid at the Florida plant, it is much more likely that most or all of the phosphorus would be shipped from Florida to one or more conversion plants located in market areas. If the Florida plant produced elemental phosphorus only, the investment would be reduced to about $30 million, and the production cost would be about $178 per metric ton of phosphorus, which is equivalent to $78 per ton of P_2O_5.

87. When the distance of the market area from the phosphate mine is such that the transportation cost is $15 per ton, the shipment of elemental phosphorus would cost about $6.60 per ton of P_2O_5 as compared with $32.60 per ton of P_2O_5 for diammonium phosphate (18-46-0), a saving of $26 per ton of P_2O_5. Under these conditions the electric furnace process would have a clear advantage when a 20 per cent return on investment is included, as shown in the following tabulation.

/...

	$/metric ton of P_2O_5
Cost of elemental phosphorus (3-mill power)	78.00
Return on investment (20 per cent/yr on $30 million)	32.40
Transportation of phosphorus	6.60
Conversion to fertilizer	10.00
Total:	127.00
Cost of wet-process acid	87.50
Return on investment (20 per cent/yr on $16.5 million)	17.84
Conversion to fertilizer	8.00
Transportation of fertilizer	32.60
Total:	145.94

In the above comparison it is assumed that the fertilizer product is ammonium phosphate, and that the cost of ammonia in the market area is the same as at the phosphate mine, so no credit for shipping the nitrogen content of ammonium phosphate is allowed.

88. Another possibility is overseas transportation of elemental phosphorus to supply fertilizers to developing countries. Ocean transportation costs for shipment of fertilizer from the United States to India are in the range of $12 to $15 per ton. Thus, shipment of triple superphosphate costs $26 to $33 per ton of P_2O_5. Ocean freight rates are not available for elemental phosphorus; at an assumed cost of $18 per ton, however, the freight per ton of P_2O_5 equivalent would be $8, and the saving over shipment of triple superphosphate would be $18 to $25 per ton of P_2O_5.

89. Comparison of the cost of shipping elemental phosphorus to India with the cost of shipping phosphate rock and sulphur is more difficult as rock and sulphur are not commonly shipped there from the United States. However, recent prices of phosphate rock and sulphur delivered at ports in India were

/...

$23 and $60 per metric ton, respectively. Thus, the raw materials for making wet-process phosphoric acid in India would cost $133 per metric ton of P_2O_5. The cost, including allowance for a 20 per cent return on investment, of elemental phosphorus delivered in India from the hypothetical Florida plant with 3-mill power is calculated to be less.

90. Concentration of wet-process phosphoric acid to superphosphoric acid for shipment to India or other developing countries has been proposed. A rough comparison gives elemental phosphorus a cost advantage over wet-process superphosphoric acid for shipment to India.

	$/metric ton of P_2O_5
Cost of elemental phosphorus (3-mill power)	78.00
Return on investment (20 per cent/yr on $30 million)	32.40
Freight to India (0.44 ton at $18)	7.92
Conversion to phosphoric acid in India	10.00
Total:	128.32
Cost of wet-process acid ($38.50 sulphur)	87.50
Conversion to superphosphoric acid	8.00
Return on investment (20 per cent/yr on $18 million)	19.40
Freight to India (1.39 tons at $15)	20.90
Total:	135.80

It is concluded that where electricity is available at or near 3 mills per kwh and sulphur costs are as high as $38.50 per ton, the electric-furnace method should be considered for phosphate fertilizer production. The usefulness of furnace acid for industrial phosphates weighs in its favour. Other favourable factors are the ability of the process to use low-grade rock, the suitability of the product for making unusually high grade fertilizers, and transportation savings through shipment of elemental phosphorus.

/...

The problems of developing countries

91. When developing countries seek to establish a fertilizer industry, they are often confronted by a bewildering array of problems and alternatives. A discussion of these problems may be of some help to those who must plan to provide for the necessary fertilizers to increase their agricultural output.

92. Developing countries often proceed with establishment of a nitrogen fertilizer industry first, then a phosphate fertilizer industry, and finally a mixed fertilizer industry. This procedure has some disadvantages. It is likely to make the total job more expensive, and it complicates the job of giving the farmer the balanced fertilizer that he needs. It would be better to start with the concept of providing the farmer with the grades of fertilizer he needs rather than thinking in terms of separate industries. In countries where farmers are well educated and where there are many well-trained agricultural advisers and ample facilities for soil analysis, the farmer can make wise use of straight fertilizers. Even so, farmers oftenprefer multi - nutrient fertilizers. In developing countries, farmers are often illiterate, well-trained advisers are few, and soil analysis laboratories may be lacking. In such cases it would seem best to provide farmers with mixed fertilizers compounded on the basis of the best information available for the crops and soils of the area and with due regard to cost.

93. If farmers are supplied with straight nitrogen fertilizers, results may be good for a few years, but the phosphorus content of the soil is soon likely to become a limiting factor. The farmers will then become disappointed in the results of fertilizer use.

94. When nitrogen and phosphate fertilizer facilities are planned separately, problems may arise that could be avoided by a more integrated approach. For instance, if urea is chosen for nitrogen fertilizer and superphosphate for phosphate fertilizer, any attempt to mix these two materials results in a wet, sticky mixture that is unusable. Also, money may be wasted in granulating

two materials in separate plants when the two could be combined and granulated in a single plant.

95. The first decision confronting developing countries in providing a fertilizer supply is whether to import finished fertilizer, fertilizer intermediates, or raw materials. The usual raw materials for phosphate fertilizer production are phosphate rock and sulphur. Few countries have both these materials, and many have neither. If we can judge by the example of developed nations, we would conclude that it is best to import only the necessary raw materials, provided that the demand is sufficient to support an economical scale of operation. Examples of countries that have built up a large phosphate industry based mainly or entirely on imported raw materials are Japan, Australia, New Zealand, Taiwan, the Netherlands, Belgium, the United Kingdom and the Federal Republic of Germany. Many other countries import their phosphate rock but use indigenous supplies of sulphur or pyrites. Several countries make extensive use of nitrophosphate processes that require no sulphur.

96. The examples mentioned above indicate that lack of indigenous raw materials does not preclude establishment of a flourishing phosphate industry. In fact, some of the above-named countries export a substantial amount of phosphate-containing fertilizer

97. It is natural that all countries should wish to make use of whatever indigenous raw materials they have. However, insistence on use of indigenous raw materials of unsuitable quality or excessive cost is a poor policy. Some examples of uneconomic use of indigenous raw materials are use of high-cost, low-grade rock that cannot be beneficiated economically. Such a policy can only lead to excessive cost of phosphate fertilizer which will discourage its use and retard agricultural development. The result is likely to be more damaging to the country's economy than importation of fertilizers or raw materials. Developing countries should search diligently

/...

for raw materials, and should evaluate carefully the economics of using any that are found.

98. The possibility of importing intermediate materials for phosphate fertilizer production is a recent development. Phosphoric acid, superphosphoric acid and elemental phosphorus have been proposed as materials that could be shipped economically from locations where they can be produced at minimum cost. These possibilities may prove attractive in some cases and should be evaluated carefully.

99. Importation of fertilizers is usual during the first stages of agricultural development when the demand is not sufficient for economical indigenous production or when demand is increasing faster than production. Use of imported fertilizers to create a market is a necessary prelude to establishment of an indigenous fertilizer industry. Careful consideration should be given to the kind of imported fertilizers with respect to cost, suitability, and compatability with future plans. When establishment of a fertilizer industry is planned, imported materials should be similar to those that will later be produced. Importation of mixed fertilizers or use of imported straight fertilizers in a mixing plant should be considered.

100. If the country already has a nitrogen industry, importation of phosphoric acid to make ammonium phosphate fertilizers should be considered. Another possibility is importation of bulk triple superphosphate (nongranular) for use in a production of mixed fertilizer by ammoniation-granulation techniques.

101. The planning of a fertilizer industry is a complicated problem which each country must solve for itself. Of primary importance is the cost of the finished fertilizers delivered to the farmer. The actual manufacturing cost often is no more than half of the final cost to the farmer. Handling, bagging, transportation, storage and distribution costs comprise a large percentage of the final cost. For these reasons, a thorough economic evaluation usually favours high-analysis products, although there are

/...

exceptions. When the nature of the crops and soils is such that sulphur is needed in fertilizer, some compromise must be reached between sulphur content and concentration of the primary nutrients.

102. One of the most difficult problems of developing countries is their failure to operate fertilizer production facilities at a high percentage of rated capacity. Modern fertilizer plants should be capable of an output of at least 90 per cent of rated capacity, even allowing for all necessary maintenance and occasional major repairs. In fact, it is not unusual to achieve a sustained output above rated capacity.

103. Many developing countries are operating their phosphate fertilizer facilities at only 50 to 60 per cent of capacity, even when higher output is urgently needed and fertilizer is imported to make up the deficit. There are many reasons for this poor record. They include shortages of raw materials, inadequate storage or transportation, lack of operating or maintenance skills, and difficulty of obtaining spare parts and other maintenance supplies. Most of these difficulties could be overcome if the government of the country concerned would assign a high priority to the attainment of maximum production in existing facilities. In many of these countries the supply of fertilizer is so vital to the nation's economy that top priority would be fully justified. There is a regrettable tendency to attach more importance to establishing new plants than to making the best use of existing ones.

104. Training of plant operating and maintenance personnel is a difficult problem. Firms which construct plants usually provide start-up services, but this is often inadequate for thorough training. Most construction firms have neither the personnel nor the know-how to train the plant operators sufficiently to ensure sustained, full-capacity operation. Good results have been achieved by employing a supervision team from an experienced operating firm for one or two years. An expenditure of this sort can yield far better return on the money invested than investing in new plants.

105. Short-sighted policies in limiting importation of raw materials, spare

/...