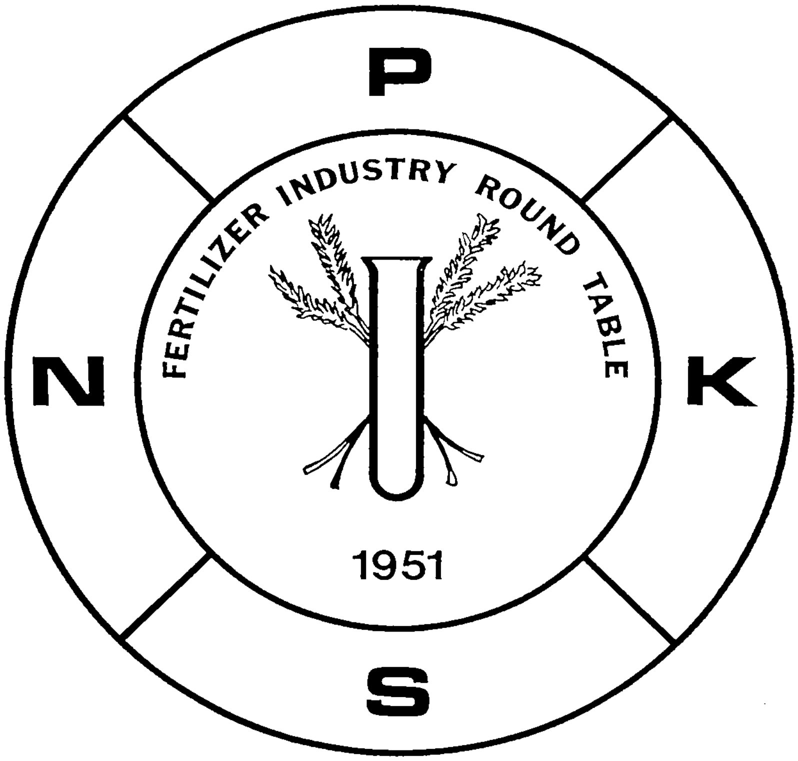
# PROCEEDINGS
# OF THE
# 39th ANNUAL MEETING
# FERTILIZER INDUSTRY
# ROUND TABLE
# 1989



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# Fertilizer Industry Round Table Award of Merit

*Presented to Rodger C. Smith by Harold Blenkhorn*

The Fertilizer Industry Round Table Award of Merit was initiated in 1986 to recognize individuals who are considered to have "advanced, promoted and contributed to the fertilizer industry to a substantial and significant degree." This year, the person chosen to be honoured with this award is Rodger Smith.

Rodger C. Smith grew up on a farm in Massachusets, and graduated from the University of Massachusets with a B.S. Degree majoring in chemistry. During World War II he served in the US Navy as a communications officer.

Rodger began his career in the fertilizer industry with Eastern States Farmers Exchange in technical development, later progressing to head of fertilizer research. In these capacities, Rodger worked in many aspects of fertilizer technology, including production, quality control, and agronomic investigations. In 1962, Amax Inc opened a potassium nitrate plant and hired Rodger to head up Market development. Rodger spent the next twenty one years with Amax, retired in 1983. At the time of his retirement he held the position of director of market development. In this capacity Rodger was in charge of market research, sales development, and technical service, domestically and abroad.

Rodger has been a director and ardent supporter of the Fertilizer Industry Round Table since its inception in 1950. Over the years, he has served as moderator at many of the technical sessions, has presented several papers, and served as Chairman in 1976-78. He has chaired various Industry committees and task forces including the TFI Government Liason committee. In 1970 he was named "Man of the Year" by the Pennsylvania Plant Food Educational Society. He has authored Chapters on fertilizer technology in American Chemical Society and Soil Science Society of America Monographs. A particularly notable contribution to fertilizer technology literature was a comprehensive chapter on potash which he contributed to the IFDC-UNIDO Fertilizer Manual.

Since retirement, Rodger has served as a consultant to several governments and corporations on marketing of potash materials, micronutrients and other chemicals. In 1983 he was leader of a US-AID team evaluating the performance of IFDC programs in lesser developed countries. Rodger and his wife Muriel reside in South Hadley, Massachussets. They have three children in differing professional fields located in Boston, Chicago, and Denver.

It is with great pleasure that I present Rodger with The Fertilizer Industry Round Table Award of Merit Plaque which bears the inscription: "In recognition of a lifetime of outstanding service and technical contributions to the Fertilizer Industry, Farmers, and People of the World, awarded this 1st day of November, 1989 to Rodger C. Smith."

# Opening Remarks

*William F. Sheldrick, Chairman*

Good morning Ladies and Gentlemen:

I should like to welcome you to the 39th meeting of the Fertilizer Industry Round Table and in particular, those of you who have come from far away places. I hope that all of you have a useful and enjoyable meeting.

I think it is appropriate that this year we are collaborating with the Fertilizer Institute on a session dedicated to "Fertilizers and the Environment" because there is no doubt that all of us will become more and more involved with this issue.

When Bob Wagner as President of the Potash and Phosphate Institute spoke to us at our meeting last year he warned us of the danger of the LISA movement and I think this warning was well justified. There are now more than sixty LISA programs operating with the support of $8 million of Federal Funds and about 40% of these projects, either by explicit or implicit reference, call for reduced fertilizer use.

In September 1989 the lengthy report by the National Research Council called "Alternative Agriculture" was published. This report which was financed by the Department of Agriculture and several other groups, recommends that Congress and the Department of Agriculture should change farm policies to encourage farmers to use less chemical fertilizers and pesticides.

I find it odd that such recommendations should be made by such a distinguished authorship on such limited, and according to some sources, questionable evidence, at a time when FAO is warning us that food stocks have fallen to their lowest level for many years and to a level which will barely guarantee World food security.

There is still a misconception that the world is wallowing in an excess of food production and that farmers in Europe and the USA are being subsidized to produce food that isn't needed. We now have a so-called "Green Movement", that wants to stop the use of chemical fertilizers, a very different movement from the "Green Revolution" that with the use of high yield variety of grains and increased fertilizer use, saved millions of people from starving in the 1960s and 1970s.

Based on information collected by FAO, it is accepted that about half the food grains produced today are the result of chemical fertilizer use and yet none of those suggesting a reduction in fertilizer use has made any value/cost estimates as to what reduced fertilizer use will mean to our farmers or World food production.

I believe that the fertilizer industry and the agricultural industry must make a major effort to counter this threat and we can do it in two ways. First we must recognize the technical problems associated with the use of chemical fertilizers and do all we can to resolve these problems in a reasonable and economic way. At the same time we have a responsibility to support our industry by countering the misconceptions that are being spread at the present time. Undoubtedly the Fertilizer Industry Round Table as an objective professional fertilizer association, through its programs, has an important part to play in this regard. Our key-note speaker today Gary D. Myers will also play a very important role.

Gary Myers is president of The Fertilizer Institute, the national association which represents all segments of the fertilizer industry.

As TFI president he serves as industry spokesman before various governmental agencies as well as the US Congress. He directs a full time, professional staff of 27 individuals who serve industry in legislative, regulatory and technical areas, as well as with information and public relations programs.

Under Gary's direction, TFI has emerged as a legislative leader in agricultural policy, trade and environmental concerns, as well as maintaining positions for industry on a number of national and state issues related to transportation, energy, safety, taxes and credit.

Gary joined the Institute in 1969 and was named its Chief executive in 1983. In a recent article in the *National Journal* magazine, TFI was singled out as among the six most effective association in Washington—a city of more than 2,000 trade groups.

Please join me in welcoming TFI president Gary Myers.

# Tuesday, October 31, 1989

## Session I
## Moderator:

## Ole Lie

## Keynote Address

### The Fertilizer Industry: Environmental Challenges, Environmental Leadership

*Gary D. Myers*
**The Fertilizer Institute**

*HOUSEHOLD WORDS*

- Organic Food
- Groundwater Contamination
- Blue Baby Syndrome
- Nitrates in Drinking Water
- Chemical-Intensive Agriculture
- LISA (Low-Input/Sustainable Agriculture)

1) I'll begin with a few of these choice words.
2) They have become common phrases among consumers, media and policymakers.
3) As one who represents the industry, I can tell you they have also been translated into an effective attack on fertilizer.

*COMMON QUESTIONS*

- Aren't There Serious Health and Environmental Problems Linked to Fertilizer Use?
- Don't Farmers Use More Fertilizer Than They Need?
- Couldn't Food Production Be Maintained Without Using Fertilizer?

1) Fundamental questions being raised about the purpose and importance of commercial fertilizer.
2) People concerned with environmental and health costs associated with fertilizer.

*FERTILIZER*

1) Fertilizer was once credited as being responsible for high levels of U.S. agricultural productivity.
2) Centerpiece of Green Revolution, foundation for export growth.

*FERTILIZER*

1) Today, few rush to defend fertilizers.
2) Concerns about groundwater contamination.
3) Organic or low-input sustainable agriculture has become newest fad.

*LISA*
(Low-Input/Sustainable Agriculture)

1) LISA—popular topic.
2) Gained supporters with few facts to back up its claims.
3) People are curious about LISA; call TFI daily to inquire about it.

*IS LISA . . .*

"A Management System Which Reduces or Eliminates the Use of Fertilizers and Pesticides, and Replaces Them with Alternative Methods"?

1) LISA has no clear definition or consensus.
2) Sustainability is most frequently defined as reduction or elimination of commercial fertilizer and pesticides.

*OR IS LISA . . .*

"A Management System Which Uses Inputs (Both Those Available on the Farm and Those Purchased) in the Most Efficient Manner Possible to Obtain Profitability from Farming, While Minimizing Effects on the Environment"?

1) Everyone supports sustainable agriculture.
2) Fertilizer played integral role in moving from dust bowl era to a system of truly sustainable agriculture.

*NO AGRONOMIC BASIS*

1) In calling for reductions, LISA supporters use no agronomic or scientific basis.

*LI$A*

1) Now everyone wants more federal funding for LISA research.
2) Land grant institutions are hustling to get a slice of the funding.
3) Never mind that the USDA has been spending $170 million on production efficiency research.
4) 100 years of agronomic research and proven results are being ignored.

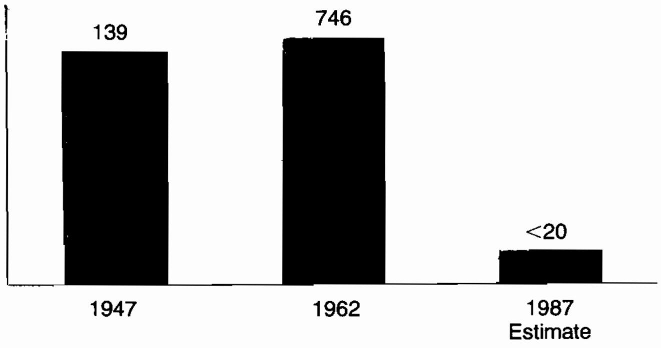
*FERTILIZER PERCEPTION VS. REALITY*

1) LISA has gained interest due to several basic misperceptions about fertilizer.
2) TFI is trying to clarify perceptions/realities about fertilizer.
3) Let's look at common perceptions—beliefs held by many people—including congressional staffs.
4) Fertilizer industry must respond to misperceptions.
2) Fertilizer industry must also improve customer efficiency and careful stewardship of environmental resources.

*PERCEPTION #1*

"Rising Nutrient Levels in Drinking Water Are Causing Serious Health Problems."

## REPORTED BLUE BABY CASES IN MINNESOTA



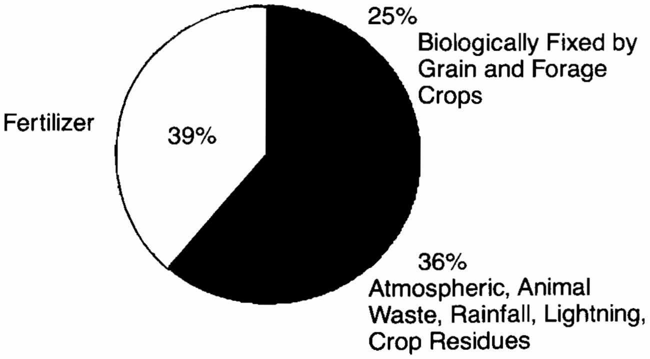
1) Only known health impact, linked to nitrate nitrogen rarely occurs today: blue baby syndrome.
2) Prior to use of commercial fertilizer: literally thousands of cases. Today virtually no reported cases.
3) In most parts of U.S., health officials have stopped keeping data due to the low incidence rate.

*PERCEPTION #2*

"Nutrients in Groundwater All Come from Fertilizer."

## NITROGEN AVAILABLE FOR FOOD PRODUCTION

### (Estimated Percentage by Source)



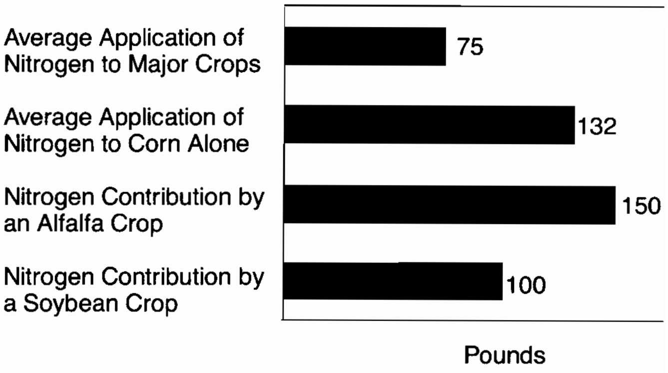
1) Statistics from the 30s and 40s—prior to commercial fertilizer use—many wells exceeded the current drinking water standard for nitrates.
2) Nutrients come from wide variety of sources—including nature.
3) Nature is not a leakproof system.

*PERCEPTION #3*

"Commercial Fertilizer is Manufactured and Therefore 'Bad', While Nutrients from Manure and Soybeans Are Natural and Therefore 'Good'."

## NITROGEN SUPPLIED BY COMMERCIAL FERTILIZER VS. NITROGEN SUPPLIED BY CROPS

### (Per Acre)



1) A nutrient is a nutrient, be it manure, soybeans, or fertilizer.
2) Nitrogen is supplied by various sources.

*"SYNTHETIC CHEMICAL FERTILIZER"*

1) Synthetic chemical has become an ominous image.
2) It has remained a continuing challenge to overcome.
3) Read box of cookies.

*PERCEPTION #4*

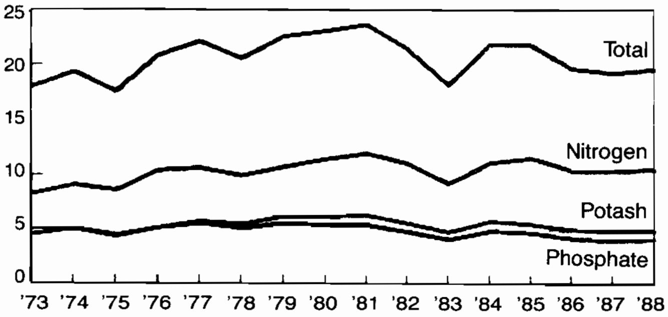
"Farmers Dump on More Fertilizer Than They Need."

*FERTILIZER APPLICATION*

- Always Based on a Soil Test
- Always Based on University Recommendations
- Never a Guessing Game

## U.S. FERTILIZER NUTRIENT CONSUMPTION

**(Million Tons)**



1) Total nutrient consumption:
   18 million in 1973
   19.5 million 15 years later.
2) Hardly a wild jump.

*PERCEPTION #5*

"Fertilizers and Pesticides Are Both Chemicals, and All Chemicals Are Harmful."

*EACH UNIQUE, EACH ESSENTIAL*

Fertilizers
  - Food for Plants
  - Nutrients Found in Nature

Pesticides
  - Shield Against Weeds and Insects
  - Generally Man-made

Both
  - Essential to Sustained Food Production

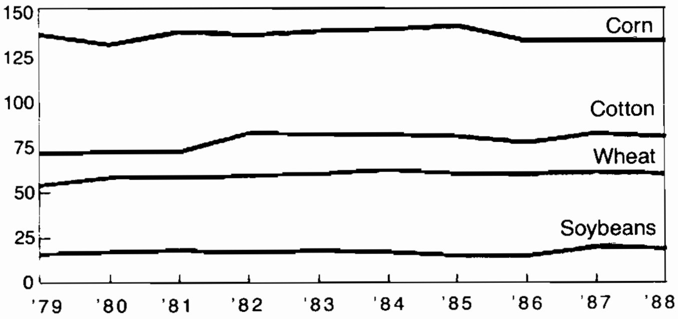
1) Fertilizer and pesticides each play unique role in food production.
2) Yet both are essential to sustained food production..
3) Distinct, but shared objective.

*PERCEPTION #6*

"Fertilizer Application Rates Are Rising Sharply."

## NITROGEN FERTILIZER APPLICATION

**(Pounds per Acre by Crop**



1) Fertilizer application rates per acre have remained virtually flat over past 10 years.
2) For example, nitrogen application on corn: 135 pounds per acre in 1979 and 132 pounds per acre in 1988. (Refer to chart).

*PERCEPTION #7*

"Farmers Can Do Without Commercial Fertilizer."

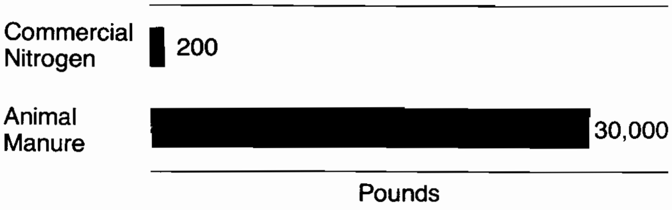
*WHY DO FARMERS USE COMMERCIAL FERTILIZER?*

- Economic and Productivity Issue
- Must Replenish Soil Nutrients to Sustain Production
- Good Soil Stewardship; Prevent Wind, Water Erosion
- No Adequate Supplies of Alternate Nutrient Sources

1) Farmers use commercial fertilizer because

## NUTRIENT EQUIVALENCE

**(Applications per Acre)**



Using Animal Manure Instead of Commercial Nitrogen—on Corn Alone—the U.S. Dairy Industry Would Need to Add 83 Million More Cattle to its Current Number.

1) Let's look at alternatives.
2) 200 lbs N vs. 80,000 lbs manure.

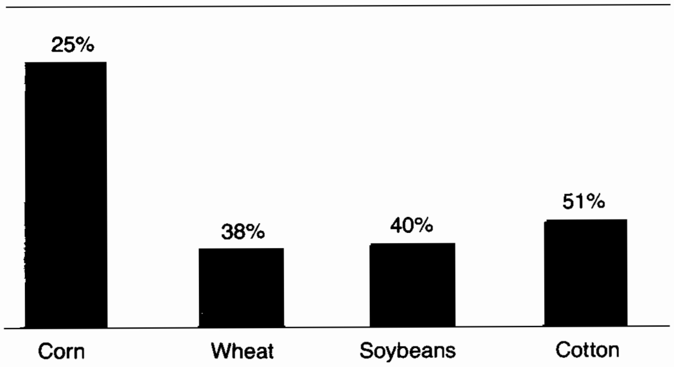
3) Just N on corn alone—83 million more cattle needed to produce enough manure.

4) Not feasible to meet needs of all U.S. farmers.

*PERCEPTION #8*

"Eliminating the Use of Fertilizer Will Have No Adverse Effect on Food Production."

### INCREASE IN PER-ACRE YIELDS
### (From 1958 to 1988)



1) Nearly half of all food production attributable to fertilizer use. (see chart)

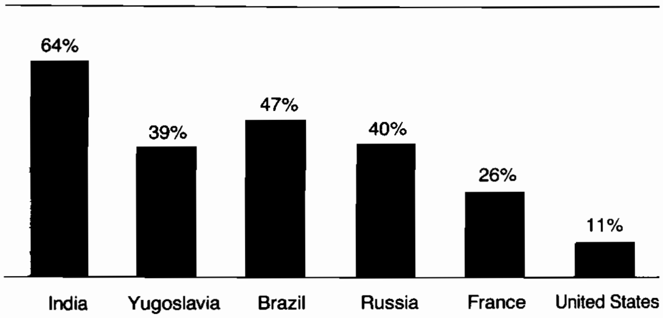
*AN ELITIST FOOD POLICY*

- Disregards Economic Impact on Consumer
- Disregards Impact on Agriculture
- Disregards Effect on World Hunger
- Disregards National Security Implications

1) Without fertilizer, food costs would increase or exports would disappear.

2) An elitist food policy: would effect those at lower rung of economic ladder.

### PERCENTAGE OF INCOME SPENT ON FOOD
### (National Averages, Selected Countries)



1) As Americans, we have good fortune of having abundant, low-cost food.

*PUBLIC POLICY IMPACT*

- Continued LISA Funding
- Proposed Farmer LISA Incentives
- New University/Extension Emphasis
- An Unreasonable National Groundwater Policy
- An Environmental Farm Bill

1) These are the perceptions driving public policy debate.

*BEST MANAGEMENT PRACTICES ARE KEY*

1) What can we do?

2) TFI is pushing a BMP education bill.

3) Would get solid agronomic BMP information to farmers.

*AGRONOMIC BEST MANAGEMENT PRACTICES CAN . . .*

- Preserve a Quality Agricultural Environment
- Maintain an Efficient Reliable Production Machine

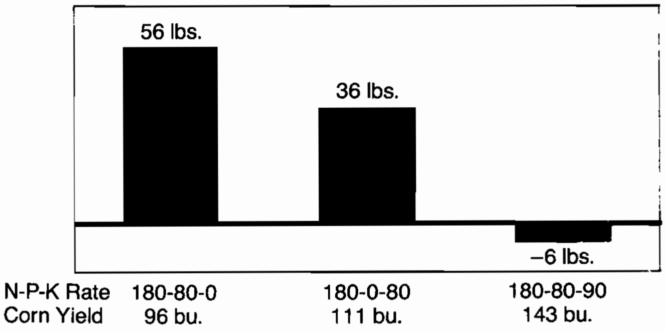
1) Each practice can reduce or prevent soil erosion and runoff from cropland, as well as nutrient losses to groundwater.

*MAKE CERTAIN CUSTOMERS KNOW IMPORTANCE OF BMPs*

1) We as an industry must educate our customer.

2) Make sure he views certain practices, such as soil testing, as essential rather than a luxury.

### NITROGEN REMAINING IN SOIL AT DIFFERING N-P-K RATES
### (Per Acre)



1) We can learn much about environmental advantages of a balanced fertility program, as we can see in this graph.

*WHAT ELSE CAN I DO?*

- Fully Inform the Community

- Illustrate Concern for the Environment
- Hold Lawmakers Accountable for LISA
- Follow an "Environmental Code of Ethics"
- Rebuild Relationships with Universities
- Remind Everyone: U.S. Farmers Feed the World

1) We must inform community of the important role of our products—partners with the farmer in an efficient production system.
2) We must illustrate our sensitivity and responsiveness to environmental concerns.
3) Call on elected leaders: stop wasting time, money and press releases on passing fancies (LISA), stick to sound, reliable, proven agronomic practices.
4) Train our people to practice environmental safety and sensitivity.
5) Rebuild our relationships with universities to ensure that rural agronomic policy is not dictated by rural social policy.
6) Remind consumers and the media that U.S. farmers feed America and much of the world, thanks to commercial fertilizer.

*WHAT IS TFI DOING?*

- Meeting with Lawmakers and Bureaucrats
- Aiming Advertising at Policymakers
- Actively Placing News Stories about Fertilizer, BMPs, and the Environment
- Conducting Radio-TV Interviews on LISA. Groundwater and Conventional Farming
- Launching Informational Effort—"Fertilizer & U.S. Farmers Feed The World"
- Conducting Gallup Poll
- "Standing Up For America's Agriculture" at Annual Dealer Conference
- Maintaining Fight for Voluntary BMP Bill

1) We are continuing efforts to make BMPs an integral part of the farm bill.
2) We want good farming practices *encouraged* by USDA rather than *regulated* by EPA.

*THE CHALLENGES ARE REAL; YOUR LEADERSHIP IS ESSENTIAL*

1) To end the misperceptions surrounding fertilizer, we must all have commitment to educate, inform, get involved, speak out, demonstrate responsibility, work closely with our customers, and always stick with the facts.
2) We are under attack in several areas in Congress:
   A) New proposals for additional LISA funding.
   B) Proposals to enact a tough national groundwater protection strategy.
   C) Plans to make 1990 Farm Bill an "Evironmental Farm Bill."
   D) New proposals to impose restrictions on farmer use of certain products, or to provide financial incentives for him to abandon conventional agriculture practices.
3) Your active involvement is essential to the industry's success in fighting these issues.
4) Count on us to stay out front—please back us up.

## Nitrogen Outlook

*Garry L. Pigg*

**Agrico Chemical Company**

It is again a pleasure to stand before the Round Table, this time to talk about the outlook for nitrogen. This year the nitrogen industry has gone through some rough periods, experiencing dramatic changes in the market. In fact, the nitrogen market has been like a roller coaster, first climbing to the peak and then crashing to almost unbelievable lows with unparalleled swings in prices.

What I hope to do today is try and explain why that roller coaster ride took place and what future rides are in store for the nitrogen industry.

I would like to address the world situation first and then discuss how the U.S. market has been impacted by current world events and what the future looks like.

As far as the world nitrogen demand outlook goes its future and growth potential appears to be secure. As you can see in Figure 1, the population of the world continues to grow by about 240,000 people per day. To feed this ever-increasing population more and more nitrogen fertilizer will be required. The relationship between nitrogen demand and population growth will over the long haul be essentially constant. Severe weather changes such as drought or monsoons have a major impact on this relationship; however, this generally is for the short term, with the following year(s) compensating for much of the variation in the effected year. Another change that could impact this relationship would be improvements in the diets of the world. This seems quite feasible in countries such as the U.S.S.R. and China to help them maintain political stability (this would be a major boost to the nitrogen industry). And, of course price related shifts in major consuming countries' buying habits can and do have major short term impacts on world trade.

Switching to supply, Figure 2 examines the production required to meet the projected 2.5% growth rate of nitrogen demand through 1992. In addition it shows both the capacity increase and the improvement in the operating efficiency needed to meet these requirements. As you can see, in 1986 the operating efficiency of installed capacity was only 79% and by 1992 that efficiency will need to climb to 87%. Figure 3 shows the developments in ammonia production since 1986 and what is required in the future to meet the expected growth rate of nitrogen consumption. The boxed-in numbers are those that have the greatest potential for variation. While nitrogen demands are growing constantly over the long term, it has been an impossible task to time production growth to meet demand over the short term. The shifting of more and more production into the Developing and Centrally Planned Countries where longer lead times for project execution are required coupled with the traditional and nontraditional short term ups and downs in the market keeps everyone guessing about the future. Higher prices in periods of higher consumption and tight supply tend to cause a real surge in new construction. And, often by the time this new capacity comes into production the world is back in an oversupply situation resulting in the opposite over-reaction of zero to too few new plants. So the nitrogen industry goes from feast to famine depending on the timing of the start-up of new capacity to meet demand. The current period we are in seems very much like a famine for the nitrogen producer; but looking at Figure 3, it is evident we could very well be in a feast situation in the near future if new plant start-ups are delayed or higher operating efficiencies in existing plants can not be attained.

Figure 4 will help identify the major growth countries throughout the world during the period 1986 through 1992. It comes as no surprise that China, India, and the Soviet Union comprise 44% of the growth in consumption of nitrogen fertilizer during this period while at the same time their production capacity increases an equivalent amount. On the other hand, while 15% of the growth in the consumption of nitrogen from 1986 to 1992 will come from the United States, only 9% of the production growth will originate there. To date the demand growth in the U.S. has been primarily the result of a net 22 million acres of farmland having gradually come back into cultivation since the 1982/83 "PIK" programs. And virtually all of the production increase has been from retrofit expansions of existing plants and from higher operating rates. Future demand trends will be a function of farmland set aside programs while production capacity is expected to remain flat or to decrease slightly. Imports have filled the gap between demand and production. This trend is not expected to change with impending energy cost increases predicted for the U.S.

Looking at nitrogen production on a world wide regional basis, Figure 5 compares ammonia production trends in the Industrially Developed Countries, Developing Countries and Centrally Planned Countries. What stands out rather dramatically in this figure is the tremendous increase of capacity in the Centrally Planned Economies. For the U.S.S.R. and East Europe this has resulted in large increases in exports—the U.S.S.R. alone in 1988 accounted for 30% of world trade of ammonia while the U.S.S.R. and East Europe accounted for 37% of world trade of urea. China's increased capacity has helped it to increase its nitrogen consumption and to dampen its import requirements.

The Developing Countries have also shown an increase in capacity over this same period with much of this going towards increasing internal consumption and reducing imports in some countries and/or providing exports. The countries rich in natural gas such as the Arabian Gulf Countries, Indonesia, Malaysia, Mexico, Nigeria, North Africa, Trinidad and Venezuela have all developed substantial ammonia and urea export capabilities. In the case of Indonesia and Nigeria internal consumption will soon eliminate exports unless additional capacity is installed.

The Industrially Developed regions of North America, West Europe and Japan have, since 1980, reduced their ammonia capacity by 6%. While there has been some new plant construction based on advanced low energy and reduced capital cost technologies and by retrofit expansions of existing plants, there has been even more capacity shutdown. As an example, in the U.S. today there are 48 "active" ammonia plants (that are operating or ready to operate) and 53 closed plants with at least 20 in some stage of being dismantled. Few if any of the inactive plants are considered likely to restart.

Thus we have seen dramatic changes in nitrogen world trade patterns over the past 25 years. And, these changes will continue.

Also we have seen the impact of dramatic shifts in major consuming countries' buying patterns on nitrogen prices—the latest just this year. Figure 6 shows the impact India's phosphoric acid contract dispute with Morocco had on the world ammonia market. While India did shift from DAP production to DAP imports during this dispute, most of this DAP came from the U.S.; however, the 400,000 metric ton drop in India's ammonia purchases was a serious blow to its traditional ammonia suppliers in the Middle East who in turn had to find new homes for their production. The result was a very aggressive Middle East which often sold its ammonia at prices below their cash cost with little or no value placed on gas. This disrupted traditional trade patterns throughout the world and the U.S. felt the impact also. As for next year, it is still in question as to when India and Morocco will resolve their differences; however it is not expected to continue much longer.

The urea market took a beating this year also, with total urea trade forecast to drop by over 2.5 million tons (See Figure 7). China who accounted for more than 42% of the urea trade in 1988 is expected to reduce their urea purchases in 1989 by this same amount (2.5 million tons). In 1990, urea trade should improve slightly with China increasing their urea purchases and India expected to return to the market after a brief absence. This recovery will be a welcome sight for the major suppliers of urea to China (Shown in Figure 8) as well as the entire nitrogen industry because, when the producer can't find a home for his urea, he sometimes will market his nitrogen as ammonia. Thus, it is truly no mystery why urea and ammonia prices dropped so dramatically during the first half of this year.

And, looking at Figure 9, it could be a long time before we see a total recovery in urea prices. With the end to the Iran/Iraq conflict these two countries have been able to return to the urea market as producer/exporters rather than importers. They have repaired many of the facilities damaged by the war and are in the process of repairing the others as well as planning to construct new capacity. This additional capacity will take a while to be absorbed in the world market thereby keeping a lid on prices.

Now let's take a closer look at the United States. The year 1989 has been one for the record books with the greatest decline in prices ever experienced for ammonia and urea. Figure 10 shows that ammonia fell from $132 per short ton FOB Gulf Coast in January to $68 in June for a $64 per short ton decrease. Over the same period urea fell from $151 per short ton to $93, a $58 decrease. Currently prices have inched back up slightly but world events will need to change for these prices to improve significantly.

Let's examine the events that have impacted the U.S. nitrogen demand and make a prediction for the future. There are five major events, that have or will have major implications on the U.S. nitrogen industry. First, as already mentioned, India and Morocco had a major phos acid contract dispute that still continues today. Second, the end to the Iraq/Iran conflict has enabled previously shutdown capacity to return to production. Third, political and foreign exchange problems had an impact on China's urea purchases. Fourth, for the second straight year the U.S. had less than optimum growing conditions. And, finally, the consolidation of the U.S. nitrogen industry has continued at an increased pace. The first three items have already been discussed so let's now take a look at the remaining two.

Figure 11 shows the growing reliance the U.S. will be placing on foreign imports to meet its nitrogen requirements. The Total Use Line in this figure includes exports and we expect a reduction in these exports which accounts for the slight downward trend in the Total Use projection. Another interesting point brought out in this figure is that, when total nitrogen use falls off in the U.S., it is the U.S. production that adjusts for the change while imports continue to increase. This practice is not expected to change in the future.

Now keying in on these U.S. ammonia imports, it can be seen from Figure 12 that in fertilizer year 1989 the U.S. experienced a dramatic 21% increase in ammonia imports with 956,000 short tons coming from Trinidad—an increase of 584,000 tons or 156% more than the previous year. In addition the Middle East became a major exporter of ammonia to the U.S. with over 200,000 short tons—last year that figure was zero. Granted, the driving force behind this increase from the Middle East was India's reduced purchases; however, it is anticipated that efforts will be made to maintain this U.S. market share if for no other reason than to have a larger customer base to dampen future shocks to their industry. Again, it is no wonder that the U.S. (and the world) ammonia price fell so dramatically from January to June of this year. Next year ammonia imports to the U.S. are expected to rise again with the modest increases expected in its gas prices.

Figure 13 shows that Trinidad's ammonia capacity increased by about 32% with the start-up of Tringen II. And, as we just saw in Figure 12, all of this additional capacity and more found it's way to the U.S. The U.S. is a natural home for Trinidad ammonia and I do not expect this to change in the near future with the Middle East and sometimes Mexico battling for any available spot sales.

Looking now at what will influence U.S. demand for nitrogen fertilizers in the next few years, Figure 14 shows that total corn, wheat, and soybean stocks are expected to be down for the third straight year in the U.S.—to what some would say are dangerous levels. This is the result of two straight years of poor weather, especially for the wheat farmers. As a result, additional acres of corn and wheat are expected to be planted next year to try and build these stocks back to more comfortable levels. Wheat stocks are so low that a new wheat program was announced this year which reduced the acreage set-aside rate from 10% last year to 5% for the coming year. The government is also allowing the farmer to plant 105% of his base wheat acreage and still be in compliance with the program. In 1990 a total of 4 million acres of idled farmland is expected to be returned to production. Figure 15 shows the historical and expected 1990 major crop acreages for the U.S. This should result in about 3% more nitrogen being consumed in the U.S. compared to last year as seen in Figure 16.

Finally, with the nitrogen industry currently in a tail spin, it is no wonder that recent asset purchases in the U.S. has a lot of people scratching their heads. Fertilizer Industries has come out of nowhere to become the largest nitrogen producer in the U.S. Farmland Industries added the Cepex plant to their capacity and Terra purchased Grace's share of their Woodward, Oklahoma joint venture. Figure 17, summarizes this recent consolidation activity. While it is yet to be seen if this consolidation will be positive for the industry in general, those of us in the business sincerely hope it will be.

*IN SUMMARY*

–The agricultural outlook for the U.S. remains strong with low grain inventories, continued strong world demand and more idled farmland being released for return to cultivation. All of these factors are encouraging news for the nitrogen industry.

–U.S. nitrogen capacity utilization will continue to decrease as more of the less efficient, older ammonia plants either shutdown or float with ammonia demand and prices.

–U.S. imports of nitrogen will continue to increase as internal production decreases and consumption increases slightly over the short term but remains essentially flat over the longer term.

–World nitrogen consumption is expected to grow in the neighborhood of 2.5% per year to provide for the increase in population.

–World trade is expected to return to a more normal pattern as India resolves its phos acid dispute and China returns to a more normal urea buying pattern. Remember, "normal pattern" as used here includes the continued shift of production capacity towards the Developing and Centrally Planned Countries who 1) have low cost natural gas and 2) are closer to those regions with projected higher demand growth rates.

–And, there will be a slight improvement in the world oversupply situation over the long term. It is suspect that all of the required new capacity increases and/or operating efficiency improvements will be completed on time; and, as further rationalization of the industry occurs in the Industrially Developed Countries, there will be further reductions of capacity in these regions.

FIGURE 1

## World Population vs. World Nitrogen Demand

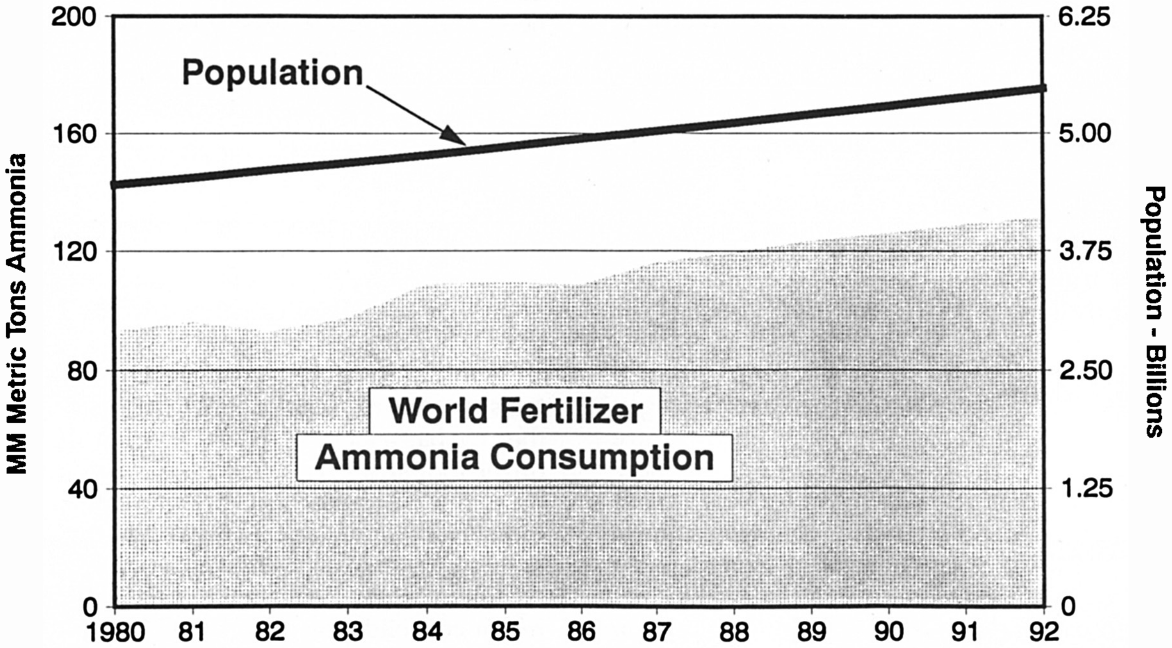


FIGURE 2

## World Ammonia Production Versus Capacity

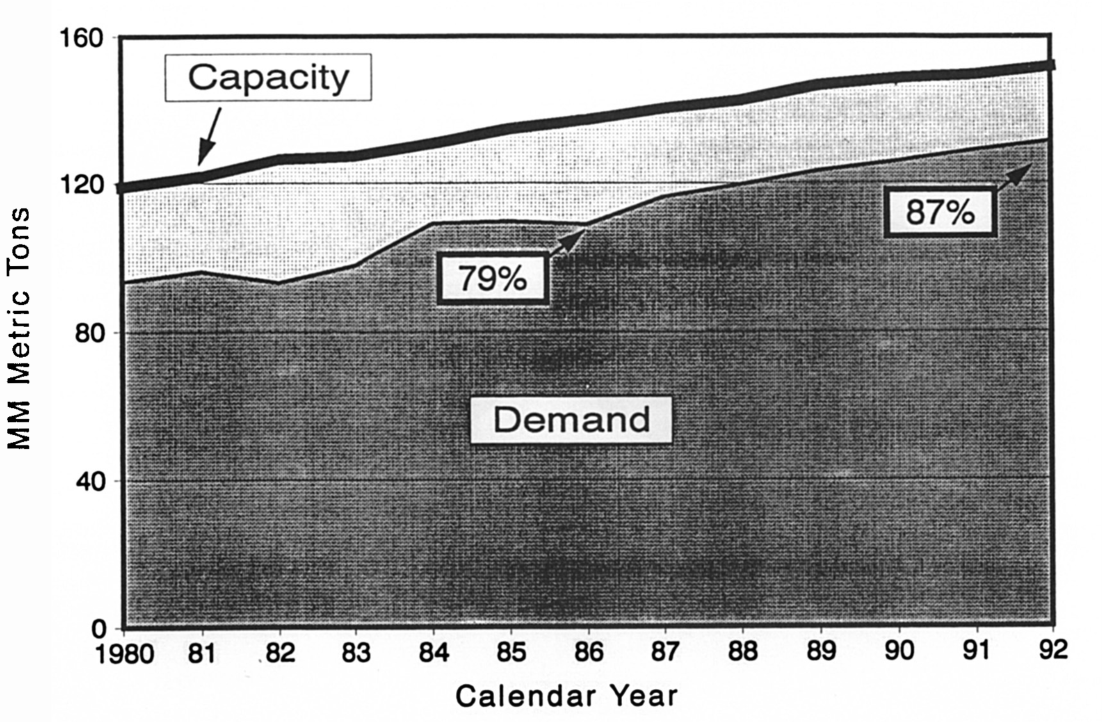


FIGURE 3

## World Ammonia Production Developments

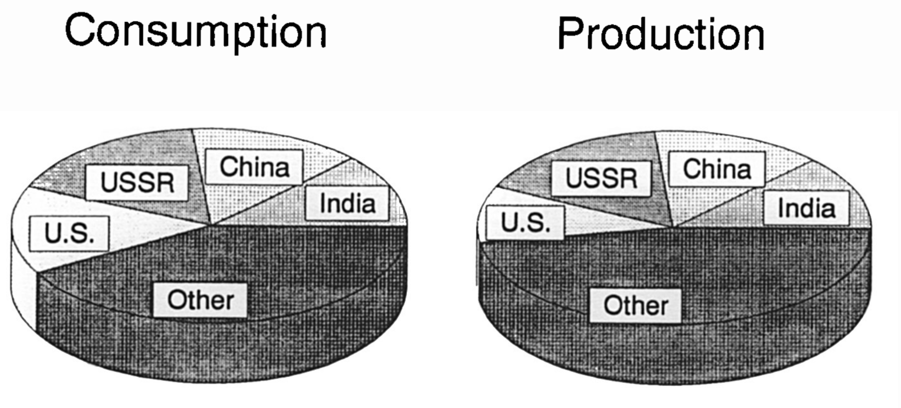
MM Tons

| | | | Capacity Factor | |
|---|---|---|---|---|
| World Production of Ammonia 1986 | | | 79% | 108.9 |
| Plant Start-ups* - | 1987-90 | 12.3 | | |
| | 1991-92 | 6.1 | | |
| Subtotal | | 17.5 | 87% | 16.0 |
| Plant Closures - | | 6.3 | 87% | (5.5) |
| Additional Production Due to 8% Higher Operating Rate | | | | 10.0 |
| Required Production to Meet 2.5% Growth Rate | | | | 129.4 |

*Includes restart and expansion of existing plants.*

FIGURE 4

# Nitrogen Growth Areas 1986-1992


Consumption

Production

| | |
|---|---|
| China | 15% |
| India | 12% |
| USSR | 17% |
| U.S. | 15% |

| | |
|---|---|
| China | 15% |
| India | 12% |
| USSR | 17% |
| U.S. | 9% |

FIGURE 5

# World Ammonia Production Capacity

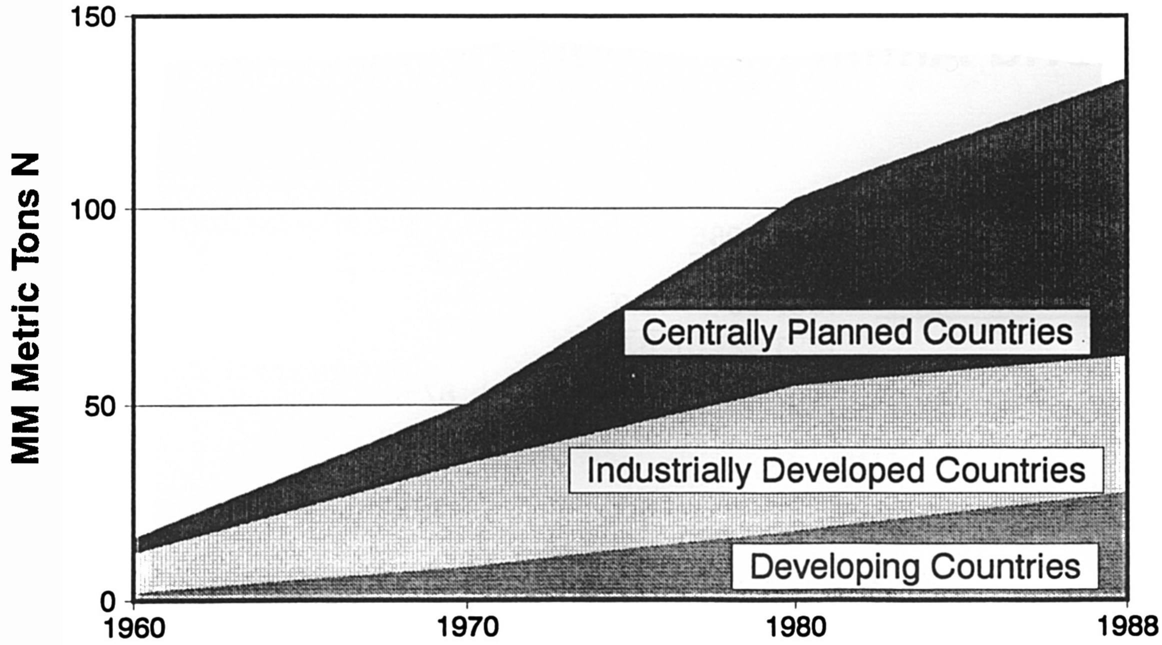


FIGURE 6

## Impact of OCP/MMTC Phosphoric Acid Impass on World Ammonia Market

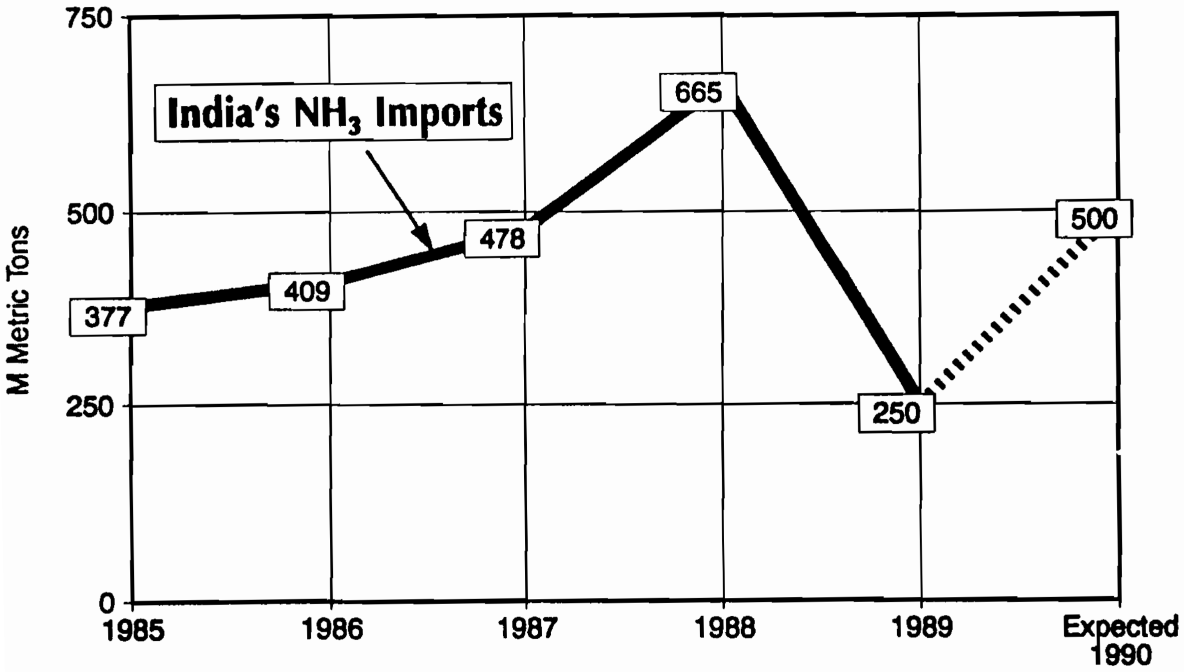


FIGURE 7

## World Urea Trade

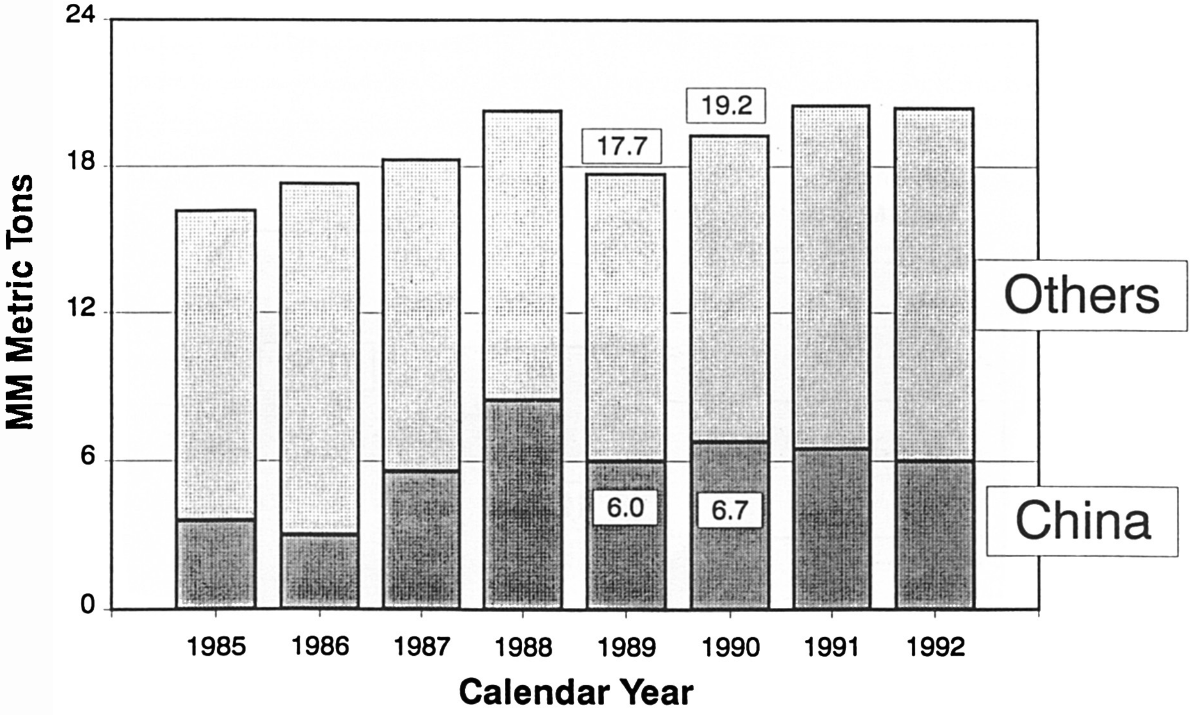


FIGURE 8

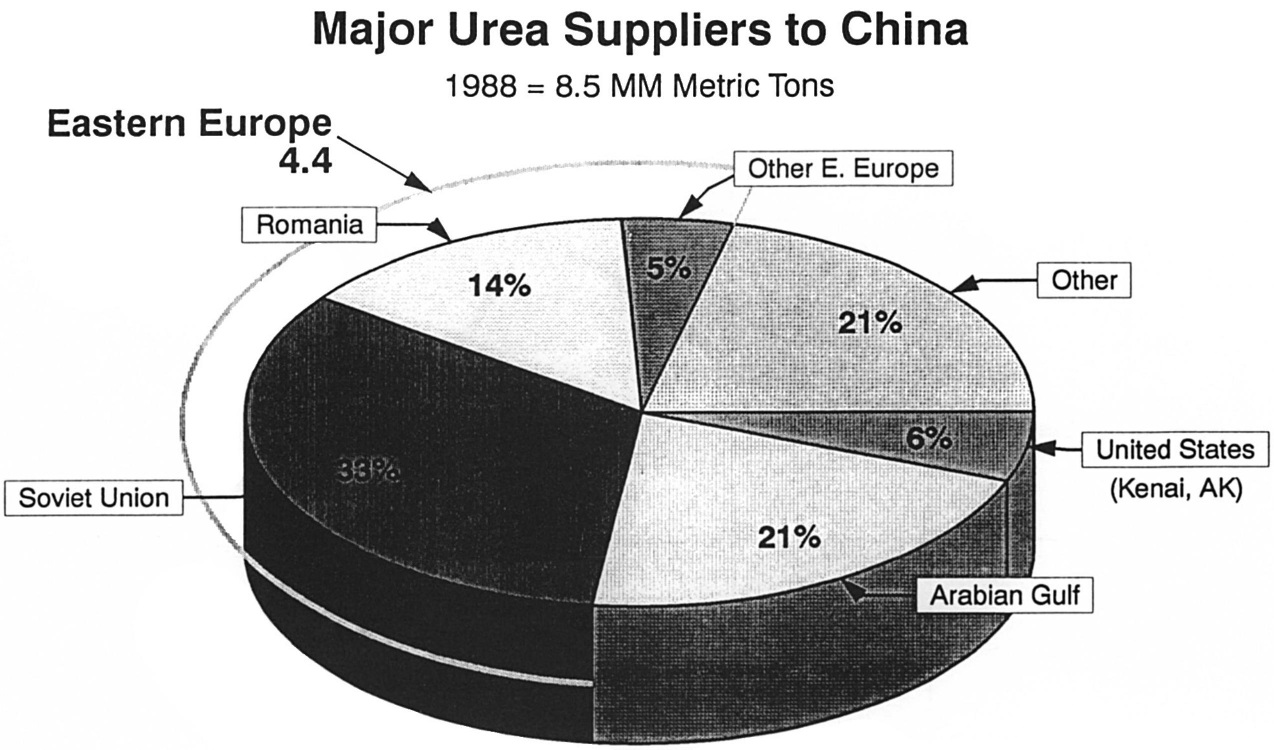


FIGURE 9

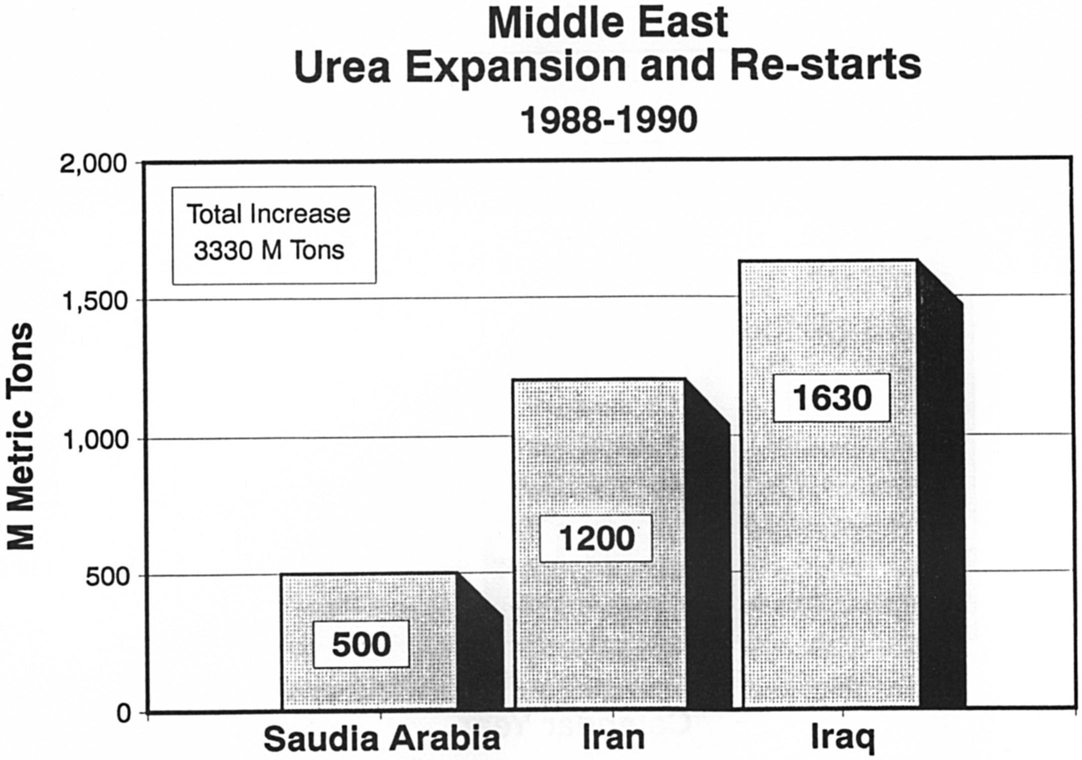
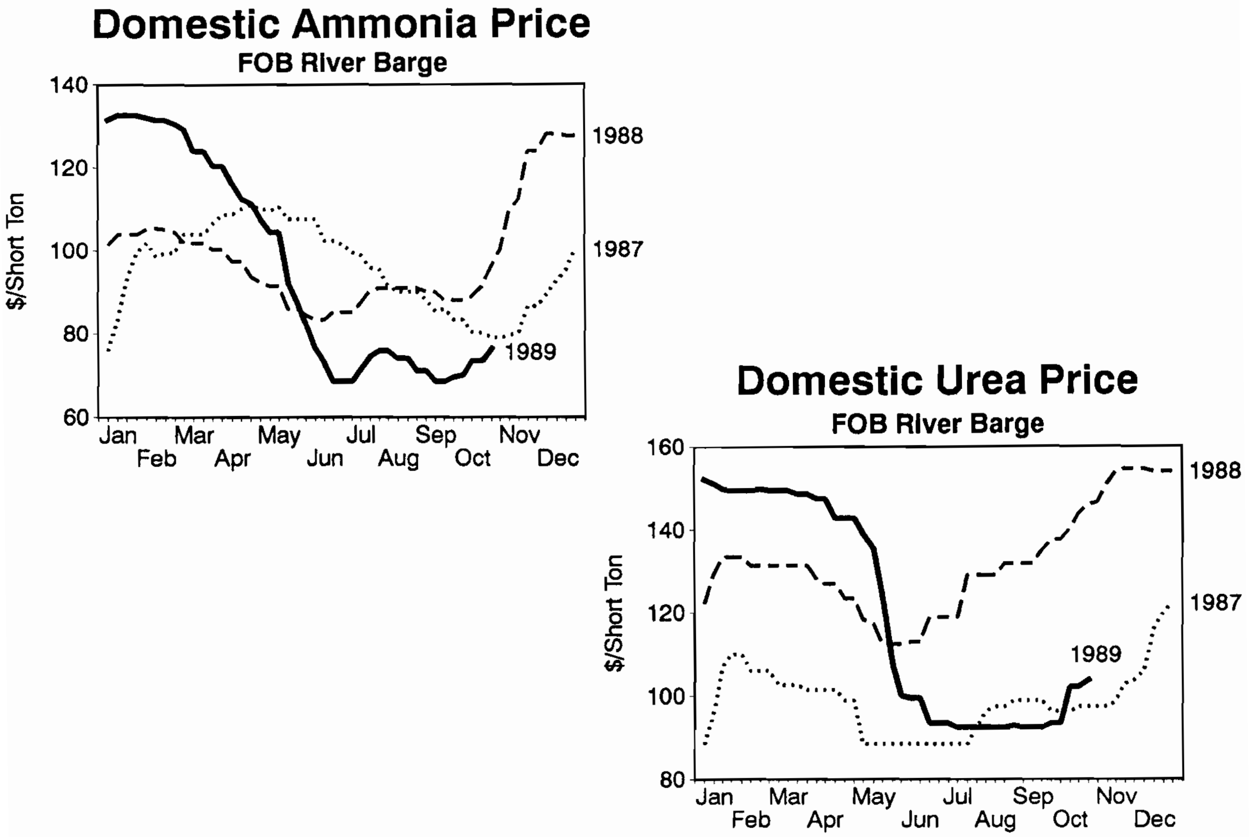


FIGURE 10



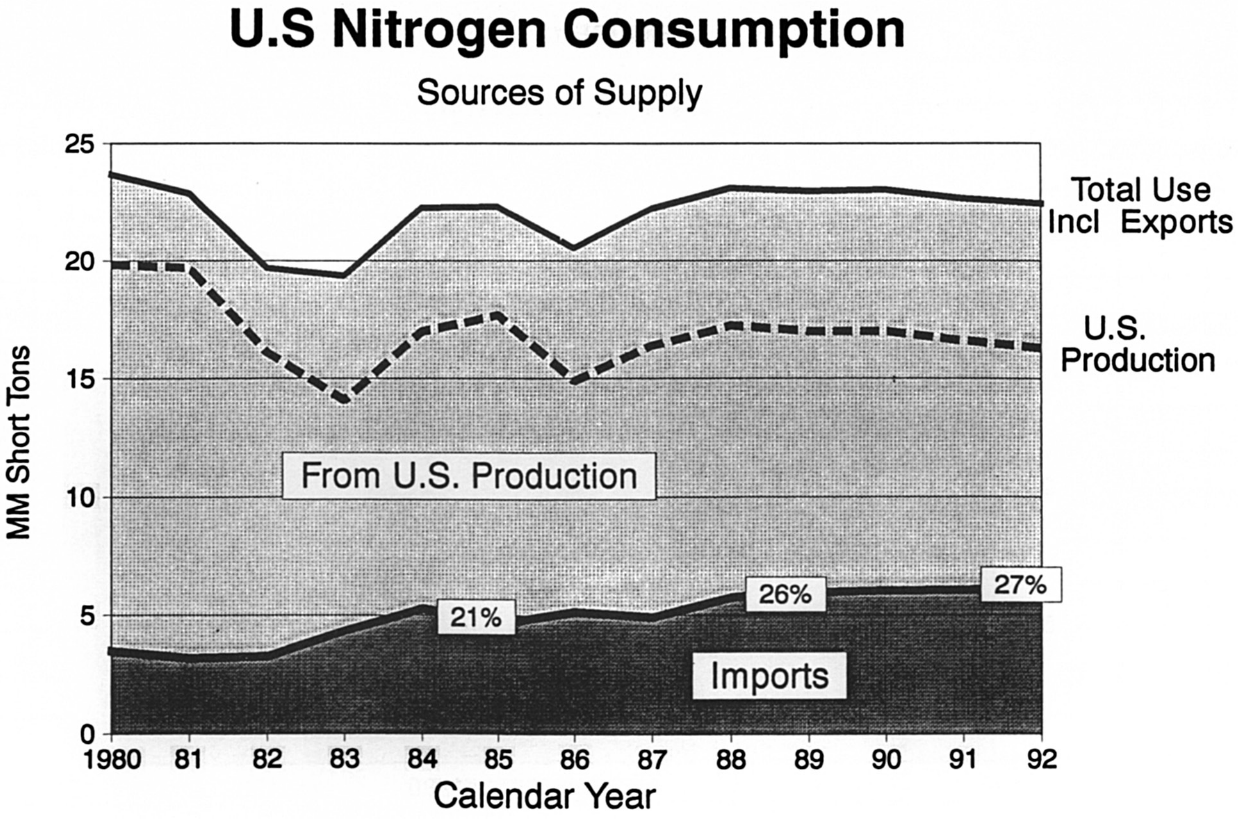
Domestic Ammonia Price

FOB River Barge

Domestic Urea Price

FOB River Barge

FIGURE 11



U.S Nitrogen Consumption

Sources of Supply

FIGURE 12

## U.S. Ammonia Imports

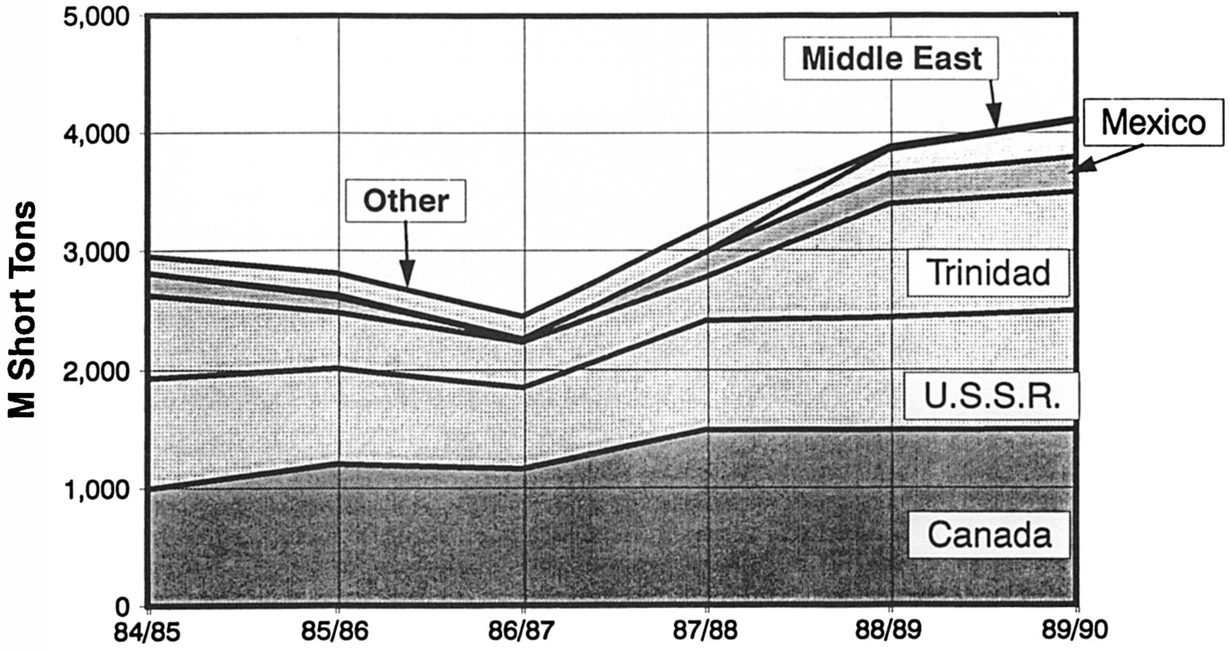


FIGURE 13

## Trinidad's Ammonia Capacity

By Source

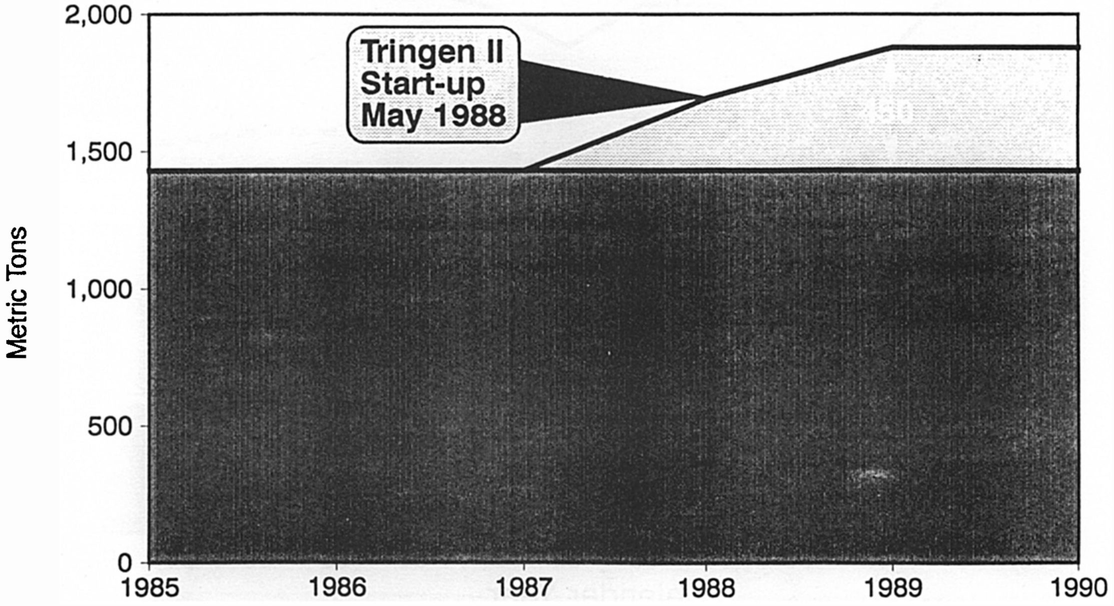


FIGURE 14

## Corn, Wheat and Soybean Stocks

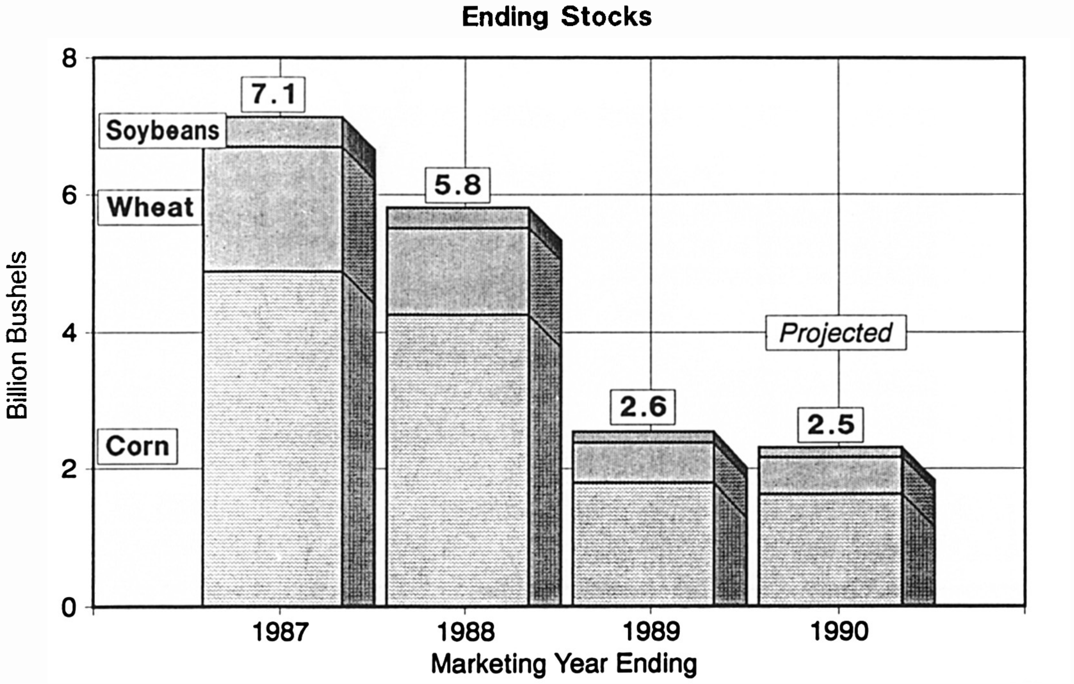
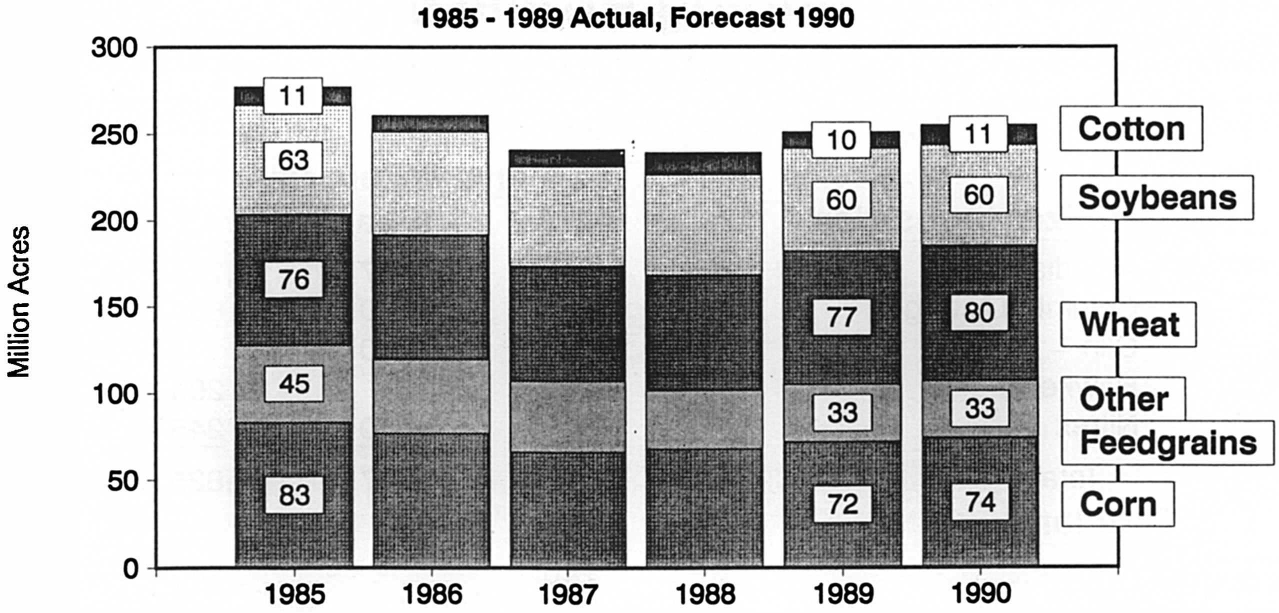


FIGURE 15

## Major Crop Acreages



| | 1985 | 1986 | 1987 | 1988 | 1989 | 1990 |
|---|---|---|---|---|---|---|
| Set-Aside Acreage | 34 | 45 | 60 | 53 | 29 | 22 |
| Conservation Reserve | 0 | 4 | 18 | 26 | 31 | 34 |
| **Total Idled** | **34** | **49** | **78** | **79** | **60** | **56** |

FIGURE 16

## U.S. Nitrogen Consumption

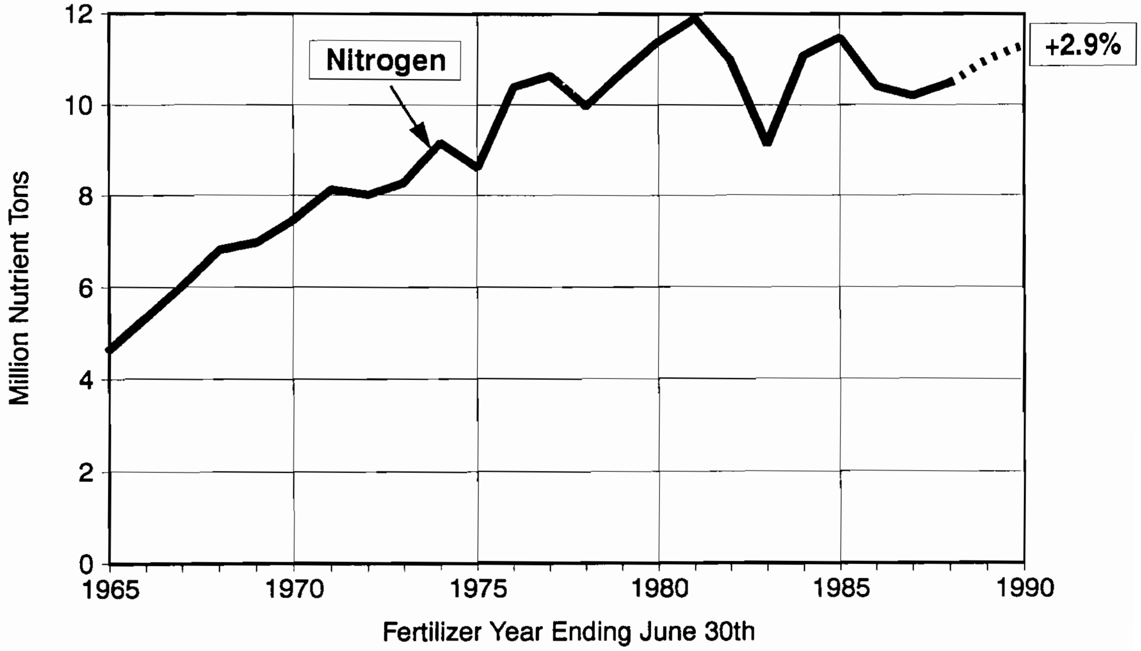


FIGURE 17

## Changing Profile of U.S. Nitrogen Industry

***Major Ownership Changes Since 1/1/88***

|  | Annual Capacity |  |  |
|---|---|---|---|
| **Fertilizer Industries** | **NH3** | **Urea** | **UAN** |
| Arcadian | 540 | 127 | 1,700 |
| * Columbia Nitrogen | 550 | 280 | 680 |
| Olin | 490 | 180 | - |
| Hawkeye | 220 | - | 200 |
| Nitrex | 340 | 350 | 245 |
| Total | 2,140 | 937 | 2,825 |
| **Farmland** |  |  |  |
| Cepex | 240 | - | 165 |
| **Terra** |  |  |  |
| Woodward - Grace's Share | 280 | - | 100 |

* *Sales Pending*

# The Outlook for Phosphates

*Ken Gilbert*

**British Sulphur Corporation**

I intend to split this presentation into three—first a quick look at history of the last 20 or so years in order to set the scene and establish the long run trends if any, second an examination of the main factors that influence the market today and finally a forecast of the outlook for phosphate fertilizers and some general comments and speculations.

In order to try to establish some long range trends I went back to our statistical data-base and asked our statistician to give me the longest consistent runs we have readily available for phosphate fertilizers production and consumption and the same for phosphoric acid. These were from 1966-1987 or 1969-1987 in the case of phosphate fertilizer production and consumption and 1977-1988 in the case of phosphoric acid.

You will all know Mark Twain's quotation "There are three kinds of lies—lies, damned lies and statistics". The numbers provided by our statistician are probably as good as any available given the attention that has been given to their compilation and that many countries do not report production or consumption. It is when they are made into a picture that editorial bias can creep in. Figure 1 shows phosphate fertilizer production from 1966-1987 and, you will agree I think, illustrates a fairly steady and predictable growth over the period. Exactly the same numbers have been used in Figure 2 to show that the market has been volatile and unpredictable. Comment is un-necessary but a second quotation, this time by Andrew Lang, is apposite "He uses statistics as a drunken man uses lampposts—for support rather than illumination".

I have examined the long run World phosphate fertilizer consumption numbers in detail and as far as I can discover there is no pattern to them whatsoever. I looked for evidence of cyclicality at 3, 4 and 5 year intervals but could find none. I conclude that the aggregate figures do not provide any guidance as to future consumption. Rather than waste the examination I would like to pass on to you the following observations, but you should not imply that the average annual growth rates quoted indicate exponential growth or any other kind of regular growth. They are merely arithmetic calculations.

The long-range look shows that phosphate fertilizers production has increased at an average annual rate of 5.5% over 18 years but that the growth rate had slowed to 1.8% over the last 7 years of the period (Figure 3). According to the statistics, consumption growth over 18 years was at the slower rate of 3.6% pa but with a less marked slackening of growth to 2.1% pa over the last 7 years of the period (Figure 4). The figures also illustrate the unsurprising fact that the important North American and Western European markets are mature and have little if any growth and that, in the period 1980-1987, East Europe, Asian CPEs and S&E Asia together accounted for 6.32 million tonnes $P_2O_5$ additional consumption (Figures 5 and 6).

The equivalent percentages for the production of wet-process phosphoric acid (Figure 7) are 3.4% and 1.3% over 1977-1988 and 1984-1988 respectively and for consumption, 3.6% and 1.8% (Figure 8). Over the period 1984-1988 East Europe, Africa and S&E Asia accounted for 2.67 million tonnes $P_2O_5$ additional consumption (Figures 9 and 10).

In the tables in the paper (some of the Figures are extracts from the tables) I also give peak year, the average tonnage made or consumed in the period 1980-1987 (or 1984-1988 in the case of phosphoric acid) and the production and consumption range for the period 1980-1987 (1984-1988).

The product mix in the phosphate fertilizer industry has shown great changes over the period (Figure 11). The most obvious change is the growth of ammonium phosphates which only represented a little over 1% of total nutrients in 1970 but over 34% in 1987. Single superphosphate and basic slag declined in percentage terms, NPKs increased.

Given the statistics but no other information about current market conditions one might draw the conclusion the consumption of phosphate fertilizers in Western Europe, North America and Oceania will remain at approximately the current level whereas growth in the rest of the World will be at a rate of about 6% pa. This converts to a World growth of about 1.3 million tonnes/a $P_2O_5$ or 4% pa.

An examination of total phosphate fertilizer trade (not including phosphoric acid) shows that volume of trade has increased faster than production or consumption—about 7.7% pa over the 12 year period 1975-1987 (Figure 12). Within phosphate fertilizer trade, DAP has been a star performer, this intermediate having had a growth rate of 9.7% over the period. DAP had a market share of 35% in 1975 and almost 44% in 1987. DAP and TSP had two thirds of the trade between them in 1987.

Phosphoric acid trade (including superphosphoric acid) (Figure 13) increased at an average rate of 15.5% pa between 1975 and 1987. Total trade in 1987 was about 4.29 million tonnes whereas inter-regional trade was about 3.31 million tonnes. The main exporters are Africa and North America and the main importers are West and East Europe and Asia.

Finally in these introductory comments I wanted to identify the 10 most important producers and consumers of phosphate fertilizers (not including phosphoric acid) (Figure 14). 8 countries are common to both lists.

It is clear that the fertilizer market knows no country boundaries—it is international and fairly homogeneous. Domestic markets cannot be isolated from the price swings in the export market. Phosphoric acid, TSP and DAP are standard products and are widely acceptable. This is good news and bad news—good news because suppliers and buyers know what they are talking about and dealing in, but bad news because relatively small swings in the balance of supply and demand for these few commodity products can have major effects on selling prices.

Over the past few years a handful of country markets have had a major effect on the state of the world phosphate fertilizer industry. The most important are the U.S.A., China and India. In the list of the World's most important consumers these countries occupied positions 3, 2 and 4 respectively in 1988. In 1988 they accounted for about 28% of World consumption. The U.S.S.R. is number 1 but has less effect on the World market than the three cited.

China and India are major importers of phosphate, the U.S.A. is a major exporter.

Taking the People's Republic of China first. China has become a major importer of DAP accounting for an estimated 26% of World trade in 1988. Imports for the last 5 years are shown in Figure 15. The thing to note is the extreme variability—the range from low to high is 1.54 million tonnes which is equivalent to about 17% of World trade. The market cannot cope with swings of this magnitude, everything else being equal, without considerable adjustments in capacity utilizations and, therefore, selling prices. The main supplier to China is the U.S.A. The U.S.A. provided 79% of China's imports of DAP in 1987 and 74% in 1988 and so it is the U.S. phosphate industry which has been the most affected by the volatile nature of this market.

Following the problems in China in mid 1989 the Chinese market for DAP went on hold. The Chinese buyers wanted to avoid all risks and as a consequence did nothing. Sellers were also concerned with the risks and in some cases with the political problems of supplying what was seen as a repressive regime. Within China it appeard that deliveries of imported fertilizers from the ports to inland destinations were dislocated and the private agricultural sector was too uncertain of the immediate future to purchase fertilizer. This period now seems to be passing and business contacts with China are picking up again.

1989 was expected to be a very good year for Chinese imports of DAP. About 700,000 tonnes of purchases made in 1988 were carried over and were shipped in the first half year. In April Sinochem made purchases from U.S. producers of a further 1.05 million tonnes for delivery during the second and third quarters and had been expected to come back to the market for a further 0.75-1.00 million tonnes for delivery in the fourth quarter 1989/first quarter 1990 and it is this tonnage which is still undecided. China is certainly in the market for DAP and may have concluded some 450,000 tonnes for shipment November 1989-January 1990 but there are rumours of shortage of free foreign exchange.

Given no further deterioration in the internal situation in China, 1990 should be a more "normal" year but as far as DAP imports are concerned there remain areas of doubt. The two new DAP plants should come on stream in 1990 and so DAP imports could suffer and be replaced by imports of phosphoric acid. All imports will be affected by foreign exchange which is likely to be short and the private sector of agriculture may remain depressed for some time.

Not only did the fertilizer market have to contend with the problems in China during the year but there was another long-running problem which had a serious effect on the market. This concerned one of our big three, India, and Morocco, the World's most important supplier of phosphoric acid to the international market.

Morocco is very dependent on India as a market for its phosphoric acid (Figure 16) and India is very dependent on Morocco as a source of phosphoric acid feedstock for its DAP plants but India can buy DAP if the prices of phosphoric acid and DAP get out of line. The two countries were unable to agree on a price for phosphoric acid for 1989 and as a consequence India turned to DAP in order to satisfy its phosphate fertilizer needs. This had a very disturbing influence on the markets for phosphoric acid and DAP. OCP had a very bad first half 1989 particularly for phosphoric acid and the U.S. picked up 1.33 million tonnes DAP business in FY 1988/89 compared to nil in FY 1987/88 (Figure 17).

There were in fact two disputes, the one I have mentioned between India and Morocco and a second between the Indian government and the Indian fertilizer industry. The first dispute was over price and it gave the Indian government the opportunity to bring forward legislative changes in the retention price system upon which the fertilizer industry had grown to depend and which had been judged to foster inefficiency. The government also seemed to want to make untenable the old concept of maintaining self-sufficiency at any price.

The conflict between the manufacture of DAP from imported phosphoric acid and the importation of DAP is not unique to India. DAP importation has consistently proved the more attractive course and industries based on imported phosphoric acid have usually needed government support in the form of subsidies and/or domestic market protection in order to survive. The Indian situation has brought this matter to the forefront with the following probably effects:

(a) Few if any DAP plants or NPK plants based on imported phosphoric acid are likely to be planned in the immediate future.

(b) Some existing units will look at the possibility of backwards integration to phosphoric acid manufacture, particularly in India.

(c) Given India's importance as a flexible purchaser of phosphoric acid and/or DAP the price relationship between phosphoric acid and DAP should achieve greater stability. Turkey is, and China will become, flexible in this regard.

(d) OCP, Morocco, has reviewed its product strategy and will opt for a much greater granulation capacity with the consequence of a reduced phosphoric acid export. The role of merchant grade phosphoric acid as a phosphate fertilizer intermediate in international trade will decline.

Turning now to U.S. phosphate fertilizer consumption we note that it is the most variable market. If U.S. consumption of wet-process phosphoric acid is taken away from World consumption then a relatively smooth growth curve is obtained for the period 1977-1987 (Figure 18). The curve is less smooth for World consumption of phosphate fertilizers less U.S. consumption over the same period (Figure 19) but a reasonable trend line could be drawn.

Consumption of phosphate fertilizer in the U.S.A. is a function of many things but it is probably most influenced by grain stocks. As Garry Pigg pointed out at the Round Table meeting last year, well over 50% of phosphate fertilizer used in the U.S. is used on corn. The correlation between corn acreage and phosphate consumption is good. We are told that acres planted to corn should be 74-78 million in 1990 up from 72.5 million in 1989. This indicates a phosphate fertilizer usage of 4.3-4.5 million tonnes in 1990.

As the World's leading "swing" producer of grains it is not surprising that there is wide variability year on year in phosphate fertilizer consumption. World grain stocks are currently very low. U.S. farmers will take advantage of the low level of global stocks and increasing grain consumption to expand production. Everything else being equal increased grain production means increased fertilizer consumption. A further incentive to fertilizer phosphate usage is low buying price. We expect World market selling prices for DAP to be slightly less in the 1st quarter 1990 than they were in 1st quarter 1989 and so at least there should be no disincentive to purchase. Of course there is a paradox. Strong demand pushes up prices which then depress demand. The recent experience of American farmers has made them more cautious and this will have a dampening effect on the degree of expansion, thus moderating the rise in fertilizer consumption.

There seems to be no mechanism known to man to prevent a very efficient agriculture like that in the U.S. from over-producing from time to time but it will probably take two good years in terms of weather and acreage sown to build up grain stocks to a problem level and thus spark new restrictions and a downturn. In the case of nitrogen fertilizers consumption in North America, which has shown a 4 year cycle in recent years, we are expecting the next low in 1992. In the case of phosphate fertilizers there is no clear pattern but there were serious falls in consumption (compared to the previous year) in 1974 (8.3%), 1977 (7.4%), 1981 (11.9%), 1982 (9.7%) and 1985 (9.8%) and so, with a little stretching of the imagination, there were falls every fourth year. On this basis 1988 should have been a bad year, but wasn't, and 1991 will be a bad year. One further comment about the North American fertilizer market is that the consumption of phosphates has been falling in relation to nitrogen in a slow but steady way (Figure 20). The N:P ratio in 1978 was 1.85, by 1987 it was 2.44. Had it still been 1.85 in 1987 then phosphate fertilizer consumption would have been 1.4 million tonnes higher then it actually was.

An added complication for U.S. phosphate fertilizer producers is their dependence on exports. Over the 5 year period 1983-87 North American phosphate fertilizer exports amounted to 40.6% of production (Figure 21). These exports include trade between the U.S. and Canada but this is not large.

Turning now to the outlook for the next 5 years. We build our forecasts from the bottom up—that is, we forecast the outlook for countries, then aggregate the tonnages to give regional and finally World figures. We expect consumption growth in East Europe, Africa, Central America, South America, Middle East, Asian CPEs and South & East Asia. West Europe will decline slightly, North America varies from year to year but is essentially on a plateau and Oceania is static. The average rate of growth 1987/88–1993/94 works out at 2.2% pa but the incremental consumption for each of the years from 1989/90 onwards varies widely and is 0.57, 0.73, 0.71, 0.64 and 1.28 million tonnes (Figure 22).

We see 1992 as being a rather depressed year for phosphate fertilizer consumption in West Europe and North America with 5.25 and 4.30 million tonnes respectively, a combined decline of 260,000 tonnes from 1991. Growth in the rest of the World in 1992 is put at 900,000 tonnes.

This forecast should not present any difficulty of supply for raw materials, intermediates and finished products with the possible exception of phosphate rock. Supplies of phosphate rock overall should be adequate—taking the phosphate fertilizer forecast and converting it to production (about 5% higher) and adding the phosphate rock required for non-fertilizer phosphates gives a total requirement for about 175 million tonnes by 1993, an increase of about 20 million tonnes from today's consumption—but there may be problems with certain qualities and in certain areas. Total phosphate rock capacity by 1993 should be around 190 million tonne if there is no further investment beyond that that is known at present and so capacity utilization could be running at 92% by that time. Historically this is a high rate and it may have implications for prices and further investment in capacity.

The forecast assumes that there will be no catastrophies, which is described nicely in the Concise Oxford Dictionary as "event subverting system of things", during the outlook period. Leaving sudden disasters aside there are things happening in the World which will probably have an enormous effect on the fertilizer industry in due course but, perhaps not in the next 5 years in any significant way. I would like to briefly touch on two such matters.

The first is what is happening in Eastern Europe. As we have seen from some of the numbers in the slides Eastern Europe is a very important consumer of fertilizers. As far as phosphates are concerned the region has a much higher per capita usage than Western Europe and North America and yet agricultural production per capita is much lower. The peoples of Eastern Europe have less food of poorer quality than people expect in the West. In a recent interview on BBC radio a leading Soviet journalist stated that the mass of the people were more interested in the provision of food than in theoretical ideas of freedom. Another spokeman, Mr. Nikolai Belov, First deputy Chairman of Goskomstat, the state statistics committee, has told a recent press conference that food production had grown in the first 9 months by only 3.2% against a planned target of 11% for the year although the grain harvest is projected at 209 million tonnes up from 195 million tonnes in 1988.

The U.S.S.R. appears to use much more phosphate fertilizer than its production of grains produced and phosphate fertilizer consumed (Figure 23), which we agree is a crude measure, is more than 3 times higher in the U.S.A. than it is in the U.S.S.R.

It is clearly not possible to turn around so huge an industry as Soviet agriculture to bring it up to modern standards of efficiency and productivity in a short space of time but when and if it is done there is a strong likelihood that consumption of fertilizers will fall due to more efficient usage (less waste, better timing, etc.). If at the same time the efficiency of production of phosphate fertilizers was to be improved then the U.S.S.R. could well reach a point where it was largely self-sufficient in these products.

Can it happen? It is early days and the whole movement may yet be put in reverse but there are signs of profound change. For example, we have been involved marginally in a venture in the Soviet Union in which a U.S. Corporation is providing expertise and technology to a plant that makes phosphates in order to improve product quality and consistency. The Russians are reported to be very receptive to suggestions for process improvements and have made available production plant for large scale trials. There are no obvious restrictions—the visitors have even been permitted to video the trials.

The second matter is the environmental revolution. I am still very sceptical of the "science" involved but I am now in no doubt that for the time being the movement is unstoppable. People really are concerned about the water which they drink, the food that they eat and the air that they breath. They also worry about the greenhouse effect, one of several scary but intangible new environmental problems. The chemical industry in which I include the fertilizer industry has a very real problem and one to which no easy solution exists. To most people chemicals are bad—they are seen as being responsible for poisoning people, animals and the planet. Balance goes out of the window. For example, it was pointed out at the European Petrochemicals Association Distribution Meeting in Venice in October 1988 that in the U.K. one member of the public has been killed in the last 16 years as a result of contact with chemicals released in a transport incident. Even if hydrocarbon fuels are included the figure is still within single figures. During the same period about 80,000 people had been killed on British roads. There is no doubt where the risks lie and where action is most needed but deaths on the roads cause barely a flicker of interest whereas there is a Major Hazards Sub-Committee examining in great detail methods of reducing the risks of moving hazardous substances.

Nearly every day in the serious British newspapers there will be an attack on some aspect of the chemical industry with a high proportion of attacks on fertilizers and agrochemicals. I am sure that the same thing is happening throughout Europe and North America. For example, in the London "Times" of 21st October 1989 there was a piece about organic gardening which contained the passage "There are signs of hope for the future: two large research projects, one in the United States and the other in Britain, have shown that organic produce was a better quality and also outyielded farms using the full chemistry of synthetic pesticides and fertilizers. In the U.S. there is now a $14 billion scheme to support farmers moving to organic methods". The writer of the "Times" piece takes it as axiomatic that synthetic fertilizers and agrochemicals are bad but provides no evidence of any sort.

Anyway the pressure is on and will intensify. The use of synthetic fertilizers will be gradually circumscribed by legislation controlling such things as timing of use and areas of restricted use and by the bandwagon effect with farmers joining the organic revolution. The effects will be greatest in countries in which food is plentiful such as West European countries and the U.S.A. which are important synthetic fertilizer consumers but where phosphate fertilizer consumption is not increasing. The conclusion must be that the environmental pressure will gradually reduce consumption of synthetic fertilizers in these regions.

The main environmental problem is with nitrates in drinking water arising from nitrogenous fertilizers leaching from the soil into surface and sub-surface waters. Phosphates are guilty by association. Phosphates can be responsible for eutrophication but phosphate fertilizers are only one of a number of phosphorus sources, others of importance being household detergents and human wastes. The substitution of manures for synthetic fertilizers would not solve the nitrates problem—in fact it could make it worse.

My hope is that people will realise before it is too late that only modern agriculture using the appropriate levels of "synthetic" fertilizers and plant protection agents can feed the world. By all means let us have detailed and rigorously scientific examinations of alternative agricultural systems and sensible measures to minimise the impact of agriculture on the natural environment but let us hope that we can move quickly to a situation where decisions are based on good information and not on emotion.

FIGURE 1

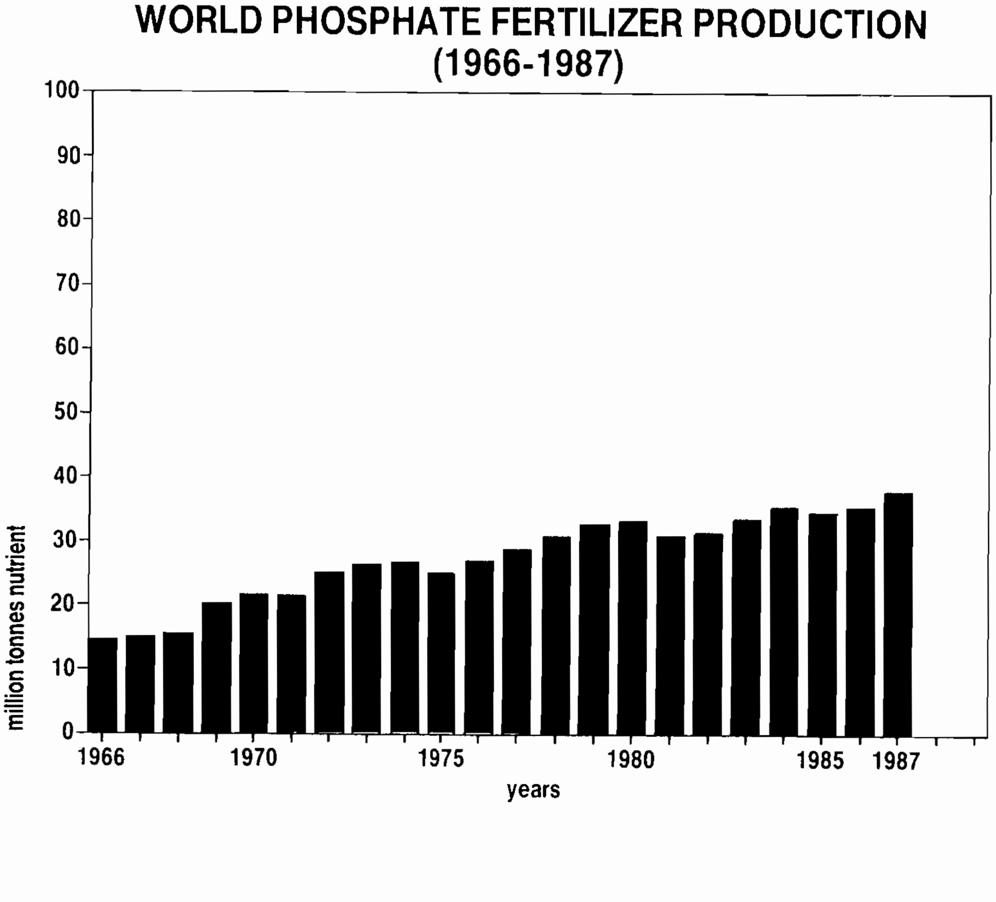


**FIGURE 2**

## WORLD PHOSPHATE FERTILIZER PRODUCTION (1966-1987)

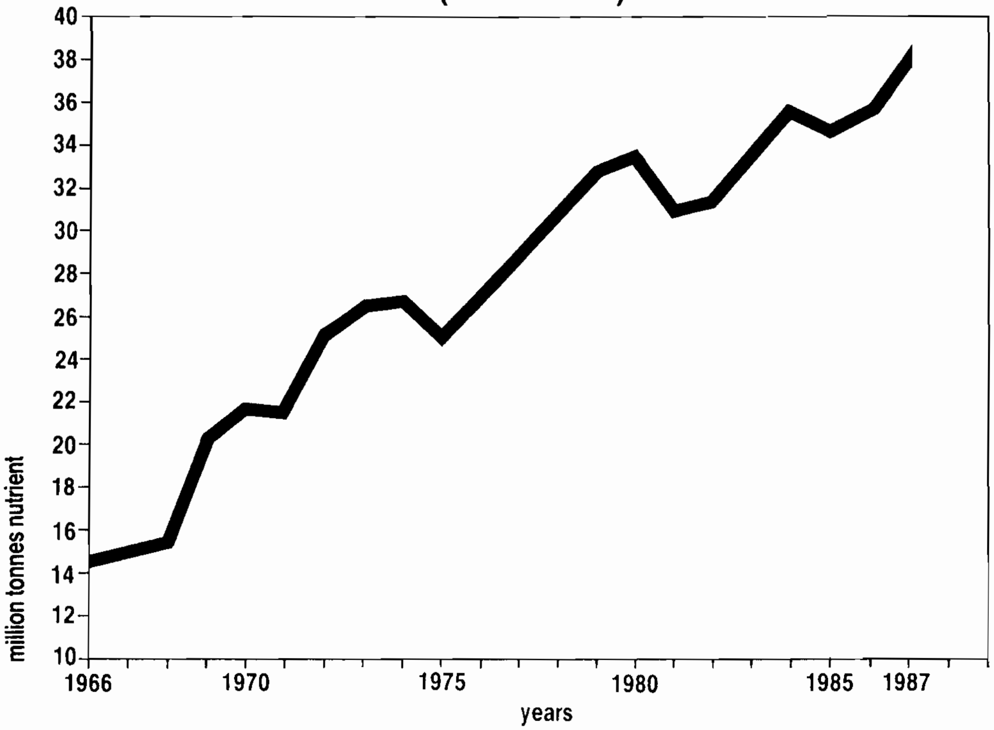


**FIGURE 3**

## PHOSPHATE FERTILIZER PRODUCTION – LONG-RANGE VIEW

(mmt = million tonnes nutrient)

| **REGION** | **Growth (Decline) 1966-1987** | | **Growth (Decline) 1980-1987** | | **Current Trend** |
|---|---|---|---|---|---|
| | **mmt** | **%pa** | **mmt** | **%pa** | |
| WEST EUROPE | 1.35 | 2.9 | 0.97 | 2.7 | plateau |
| EAST EUROPE | 7.94 | 5.4 | 2.80 | 3.9 | up |
| AFRICA | 1.81 | 20.8 | 0.65 | 6.4 | up |
| NORTH AMERICA | 3.60 | 2.6 | **(0.62)** | **(1.0)** | ? |
| CENTRAL AMERICA | 0.25 | 4.4 | 0.22 | 10.6 | up? |
| SOUTH AMERICA[1] | 1.38 | 11.6 | **(0.13)** | **(1.6)** | plateau |
| MIDDLE EAST[1] | 0.68 | 14.8 | 0.59 | 25.3 | up |
| ASIAN CPEs | 3.02 | 10.8 | 0.93 | 4.7 | plateau? |
| S & E ASIA[1] | 2.63 | 6.5 | 1.40 | 6.6 | up |
| OCEANIA[1] | **(0.22)** | **(1.2)** | **(0.32)** | **(4.3)** | plateau |
| **WORLD TOTAL[1]** | **23.48** | **5.5** | **4.55** | **1.8** | **up** |

Note: [1]1969-1987

### FIGURE 4

## PHOSPHATE FERTILIZER CONSUMPTION – LONG-RANGE VIEW

(mmt = million tonnes nutrient)

| **REGION** | **Growth (Decline) 1966-1987** | | **Growth (Decline) 1980-1987** | | **Current Trend** |
|---|---|---|---|---|---|
| | **mmt** | **%pa** | **mmt** | **%pa** | |
| WEST EUROPE[1] | 0.01 | nil | **(0.38)** | **(1.0)** | plateau |
| EAST EUROPE | 7.64 | 5.4 | 2.73 | 4.0 | up |
| AFRICA | 1.06 | 34.8 | **(0.03)** | **(0.5)** | plateau |
| NORTH AMERICA | 0.48 | 0.6 | **(1.20)** | **(3.5)** | plateau |
| CENTRAL AMERICA[1] | 0.20 | 2.3 | 0.14 | 3.9 | up |
| SOUTH AMERICA[1] | 1.82 | 9.4 | **(0.08)** | **(1.6)** | up |
| MIDDLE EAST[1] | 0.70 | 12.1 | 0.40 | 10.4 | up |
| ASIAN CPEs | 4.10 | 12.3 | 1.66 | 6.8 | up |
| S & E ASIA[1] | 3.61 | 7.6 | 1.93 | 7.3 | up |
| OCEANIA[1] | **(0.07)** | **(0.04)** | **(0.16)** | **(2.0)** | plateau |
| **WORLD TOTAL[1]** | **17.13** | **3.6** | **5.01** | **2.1** | **up** |

Note: [1]1969-1987

### FIGURE 5

## PHOSPHATE FERTILIZER PRODUCTION – LONG-RANGE VIEW

(mmt = million tonnes nutrient)

| **REGION** | **Peak Year 1966-1987** | | **Average Production 1988-1987** | **Production Range 1980-1987** |
|---|---|---|---|---|
| | **Year** | **mmt** | **mmt/a** | **mmt/a** |
| WEST EUROPE | 1974 | 6.58 | 5.18 | 4.72-5.73 |
| EAST EUROPE | 1987 | 11.83 | 10.33 | 9.03-11.83 |
| AFRICA | 1987 | 1.85 | 1.62 | 1.20-1.85 |
| NORTH AMERICA | 1979 | 9.25 | 8.13 | 6.93-9.19 |
| CENTRAL AMERICA | 1987 | 0.43 | 0.28 | 0.21-0.43 |
| SOUTH AMERICA[1] | 1980 | 1.73 | 1.45 | 1.13-1.73 |
| MIDDLE EAST[1] | 1987 | 0.74 | 0.46 | 0.13-0.74 |
| ASIAN CPEs | 1987 | 3.42 | 2.64 | 1.94-3.42 |
| S & E ASIA[1] | 1987 | 3.88 | 3.09 | 2.40-3.88 |
| OCEANIA[1] | 1973 | 1.61 | 0.97 | 0.79-1.24 |
| **WORLD TOTAL[1]** | **1987** | **38.01** | **34.15** | **30.86-38.01** |

Note: [1]1969-1987

FIGURE 6

## PHOSPHATE FERTILIZER CONSUMPTION – LONG-RANGE VIEW

(mmt = million tonnes nutrient)

| **REGION** | **Peak Year 1966-1987** | | **Average Consumption 1980-1987** | **Consumption Range 1980-1987** | **Current Trend** |
|---|---|---|---|---|---|
| | **Year** | **mmt** | **mmt/a** | **mmt/a** | |
| WEST EUROPE[1] | 1979 | 6.80 | 5.57 | 5.37-5.86 | plateau |
| EAST EUROPE | 1986 | 11.51 | 9.92 | 8.75-11.51 | up |
| AFRICA | 1981 | 1.30 | 1.17 | 1.06-1.30 | plateau |
| NORTH AMERICA | 1978 | 5.71 | 4.79 | 4.30-5.58 | plateau |
| CENTRAL AMERICA[1] | 1982 | 0.67 | 0.57 | 0.47-0.67 | up |
| SOUTH AMERICA[1] | 1980 | 2.35 | 1.86 | 1.30-2.35 | up |
| MIDDLE EAST[1] | 1987 | 0.80 | 0.62 | 0.40-0.80 | up |
| ASIAN CPEs | 1987 | 4.49 | 3.43 | 2.76-4.49 | up |
| S & E ASIA[1] | 1987 | 4.93 | 3.90 | 3.01-4.93 | up |
| OCEANIA[1] | 1973 | 1.77 | 1.10 | 0.92-1.25 | plateau |
| **WORLD TOTAL[1]** | **1987** | **36.60** | **33.05** | **30.71-36.60** | **up** |

Note: [1] 1969-1987

FIGURE 7

## PHOSPHORIC ACID PRODUCTION – LONG-RANGE VIEW

(mmt = million tonnes)

| **REGION** | **Growth (Decline) 1977-1988** | | **Growth (Decline) 1984-1988** | | **Current Trend** |
|---|---|---|---|---|---|
| | **mmt** | **%pa** | **mmt** | **%pa** | |
| WEST EUROPE | **(0.16)** | **(0.5)** | **(0.39)** | **(2.9)** | plateau |
| EAST EUROPE | 2.58 | 5.7 | 1.15 | 5.8 | up |
| AFRICA | 3.33 | 12.0 | 1.71 | 12.1 | up |
| NORTH AMERICA | 0.56 | 0.6 | **(1.76)** | **(4.9)** | up |
| CENTRAL AMERICA | 0.12 | 2.7 | 0.15 | 10.1 | up |
| SOUTH AMERICA | 0.57 | 13.2 | 0.09 | 3.0 | up |
| MIDDLE EAST | 0.56 | 11.7 | 0.16 | 5.5 | up |
| ASIAN CPEs | insig | insig | insig | insig | na |
| S & E ASIA | 0.47 | 3.1 | 0.21 | 3.4 | down |
| OCEANIA | **(0.07)** | **(4.7)** | no change | | plateau |
| **WORLD TOTAL** | **8.00** | **3.4** | **1.33** | **1.3** | **up** |

## FIGURE 8

# PHOSPHORIC ACID CONSUMPTION – LONG-RANGE VIEW

(mmt = million tonnes)

| REGION | Growth (Decline) 1977-1988 |  | Growth (Decline) 1984-1988 |  | Current Trend |
|---|---|---|---|---|---|
|  | mmt | %pa | mmt | %pa |  |
| WEST EUROPE | 0.30 | 0.8 | **(0.37)** | **(2.4)** | up |
| EAST EUROPE | 3.28 | 6.6 | 1.23 | 5.4 | up |
| AFRICA | 1.26 | 10.2 | 0.70 | 12.0 | up |
| NORTH AMERICA | 0.72 | 0.8 | **(1.06)** | **(3.1)** | up |
| CENTRAL AMERICA | 0.21 | 5.2 | 0.17 | 11.6 | up |
| SOUTH AMERICA | 0.35 | 3.7 | 0.09 | 2.3 | up? |
| MIDDLE EAST | 0.51 | 11.4 | 0.23 | 9.5 | up |
| ASIAN CPEs | insig | insig | insig | insig | na |
| S & E ASIA | 1.76 | 7.3 | 0.74 | 6.6 | up |
| OCEANIA | **(0.02)** | **(0.9)** | 0.05 | 9.7 | up |
| **WORLD TOTAL** | **8.41** | **3.6** | **1.80** | **1.8** | **up** |

## FIGURE 9

# PHOSPHORIC ACID PRODUCTION – LONG-RANGE VIEW

(mmt = million tonnes)

| REGION | Peak Year 1977-1988 |  | Average Consumption 1984-1988 | Consumption Range 1984-1988 | Current Trend |
|---|---|---|---|---|---|
|  | Year | mmt | mmt/a | mmt/a |  |
| WEST EUROPE | 1980 | 3.67 | 3.32 | 3.18-3.58 | plateau |
| EAST EUROPE | 1988 | 5.66 | 5.16 | 4.51-5.66 | up |
| AFRICA | 1988 | 4.66 | 3.46 | 2.76-4.66 | up |
| NORTH AMERICA | 1984 | 10.17 | 8.27 | 7.29-10.17 | up |
| CENTRAL AMERICA | 1987 | 0.50 | 0.39 | 0.31-0.50 | up |
| SOUTH AMERICA | 1988 | 0.76 | 0.70 | 0.68-0.76 | up |
| MIDDLE EAST | 1987 | 0.83 | 0.73 | 0.64-0.83 | up |
| ASIAN CPEs | na | insig | insig | na | na |
| S & E ASIA | 1986 | 1.75 | 1.63 | 1.43-1.75 | down |
| OCEANIA | 1979 | 0.19 | 0.12 | 0.11-0.13 | plateau |
| **WORLD TOTAL** | **1988** | **25.75** | **23.82** | **22.64-25.75** | **up** |

FIGURE 10

## PHOSPHORIC ACID CONSUMPTION – LONG-RANGE VIEW

(million tonnes $P_2O_5$)

| REGION | Peak Year 1977-1988 |  | Average Consumption 1984-1988 | Consumption Range 1984-1988 | Current Trend |
|---|---|---|---|---|---|
|  | Year | mmt | mmt/a | mmt/a |  |
| WEST EUROPE | 1984 | 4.16 | 3.83 | 3.60-4.16 | up |
| EAST EUROPE | 1988 | 6.49 | 6.05 | 5.25-6.49 | up |
| AFRICA | 1988 | 1.93 | 1.49 | 1.22-1.93 | up |
| NORTH AMERICA | 1980 | 9.26 | 7.91 | 6.83-9.18 | up |
| CENTRAL AMERICA | 1987 | 0.50 | 0.39 | 0.31-0.50 | up |
| SOUTH AMERICA | 1987 | 1.13 | 1.00 | 0.79-1.13 | up? |
| MIDDLE EAST | 1987 | 0.76 | 0.63 | 0.51-0.76 | up |
| ASIAN CPEs | na | na | insig | na | na |
| S & E ASIA | 1988 | 3.26 | 2.86 | 2.52-3.26 | up |
| OCEANIA | 1980 | 0.20 | 0.14 | 0.11-0.16 | up |
| **WORLD TOTAL** | **1988** | **26.07** | **24.32** | **23.17-26.07** | **up** |

FIGURE 11

## PHOSPHATE FERTILIZERS – PRODUCTION BY TYPE

(mmt = million tonnes nutrient)

| TYPE | 1970 |  | 1980 |  | 1987 |  |
|---|---|---|---|---|---|---|
|  | mmt | % | mmt | % | mmt | % |
| SSP | 7.06 | 32.62 | 7.31 | 21.85 | 7.06 | 18.57 |
| TSP | 3.10 | 14.33 | 5.17 | 15.46 | 5.34 | 14.05 |
| BASIC SLAG | 1.29 | 5.96 | 0.75 | 2.24 | 0.41 | 1.08 |
| NPK FERTS | 2.81 | 12.99 | 5.38 | 16.08 | 6.67 | 17.55 |
| DAP | 0.02 | 0.09 | 6.33 | 18.92 | 7.93 | 20.86 |
| MAP | 0.01 | 0.05 | 3.10 | 9.27 | 4.44 | 11.68 |
| OTHERS | 7.35 | 33.96 | 5.41 | 16.17 | 6.16 | 16.21 |
| **TOTAL** | **21.64** |  | **33.45** |  | **38.01** |  |

## FIGURE 12

# PHOSPHATE FERTILIZER TRADE – LONG-RANGE VIEW

(mmt = million tonnes nutrient)

| YEAR | TOTAL PHOSPHATE | TSP | | DAP | | TSP + DAP | |
|---|---|---|---|---|---|---|---|
| | mmt | mmt | % | mmt | % | mmt | % |
| 1975 | 3.82 | 0.94 | 24.61 | 1.34 | 35.08 | 2.28 | 59.69 |
| 1987 | 9.29 | 2.14 | 23.04 | 4.07 | 43.81 | 6.21 | 66.85 |
| CHANGE 1975-87 % pa | 7.69 | | 7.10 | | 9.70 | | 8.71 |

## FIGURE 13

# PHOSPHORIC ACID TRADE – LONG RANGE VIEW

(mmt = million tonnes nutrient)

| REGION | EXPORTS (IMPORTS) | | CHANGE |
|---|---|---|---|
| | 1975 | 1987 | |
| WEST EUROPE | **(0.01)** | **(0.59)** | **(0.58)** |
| EAST EUROPE | **(0.06)** | **(1.00)** | **(0.94)** |
| AFRICA | 0.10 | 2.01 | 1.91 |
| NORTH AMERICA | 0.22 | 1.25 | 1.03 |
| CENTRAL AMERICA | 0.09 | neg | 0.09 |
| SOUTH AMERICA | **(0.21)** | **(0.45)** | **(0.24)** |
| MIDDLE EAST | 0.01 | 0.05 | 0.04 |
| ASIAN CPEs | neg | neg | na |
| S & E ASIA | **(0.12)** | **(1.20)** | **(1.08)** |
| OCEANIA | neg | **(0.06)** | **(0.06)** |

(figures include superphosphoric acid)

## FIGURE 14

# PHOSPHATE FERTILIZERS
# TOP TEN PRODUCERS AND CONSUMERS 1987/88

(mmt = million tonnes nutrient)

| | PRODUCERS | | | CONSUMERS | |
|---|---|---|---|---|---|
| Rank | Country | mmt | Rank | Country | mmt |
| 1 | USSR | 8.84 | 1 | USSR | 8.56 |
| 2 | USA | 8.13 | 2 | CHINA | 4.30 |
| 3 | CHINA | 3.24 | 3 | USA | 3.73 |
| 4 | INDIA | 1.69 | 4 | INDIA | 2.28 |
| 5 | BRAZIL | 1.47 | 5 | BRAZIL | 1.65 |
| 6 | FRANCE | 0.96 | 6 | FRANCE | 1.41 |
| 7 | POLAND | 0.94 | 7 | POLAND | 0.84 |
| 8 | AUSTRALIA | 0.71 | 8 | AUSTRALIA | 0.82 |
| 9 | ROMANIA | 0.69 | 9 | ITALY | 0.78 |
| 10 | TURKEY | 0.62 | 10 | GERMANY | 0.68 |
| | **TOTAL** | **27.29** | | **TOTAL** | **25.05** |
| | **% of WORLD** | **71.80** | | **% of World** | **68.44** |

## FIGURE 15

# CHINA: IMPORTS OF DAP

(million tonnes product)

| | 1984 | 1985 | 1986 | 1987 | 1988e |
|---|---|---|---|---|---|
| Imports | 2.53 | 1.27 | 0.99 | 1.96 | 2.4 |
| As a % of World trade | 29 | 28 | 13 | 22 | 26 |

e = estimate

FIGURE 16

## OCP, MOROCCO, PHOSPHATE EXPORTS
(thousand tonnes $P_2O_5$)

| | 1988 | Jan-June 1988 | Jan-June 1989 | change |
|---|---|---|---|---|
| MGA | 1716 | 824 | 137 | -687 |
| TSP | 286 | 149 | 128 | -21 |
| MAP | 113 | 70 | 16 | -54 |
| DAP | 394 | 43 | 142 | 99 |
| **TOTAL** | **2509** | **1086** | **423** | **-663** |
| **MGA TO INDIA** | **964** | **420** | **nil** | **-423** |

FIGURE 17

## USA – INDIA DAP TRADE
(million tonnes product)

**USA SHIPMENTS TO INDIA**

| | FY 1987/88 | FY 1988/89 | |
|---|---|---|---|
| | nil | 1.33 | |
| **INDIA: IMPORTS OF DAP** | | | |
| TOTAL | 0.67 | 0.02 | 0.85 |
| of which: | | | |
| USA | 0.44 | 0.02 | 0.58 |

FIGURE 18

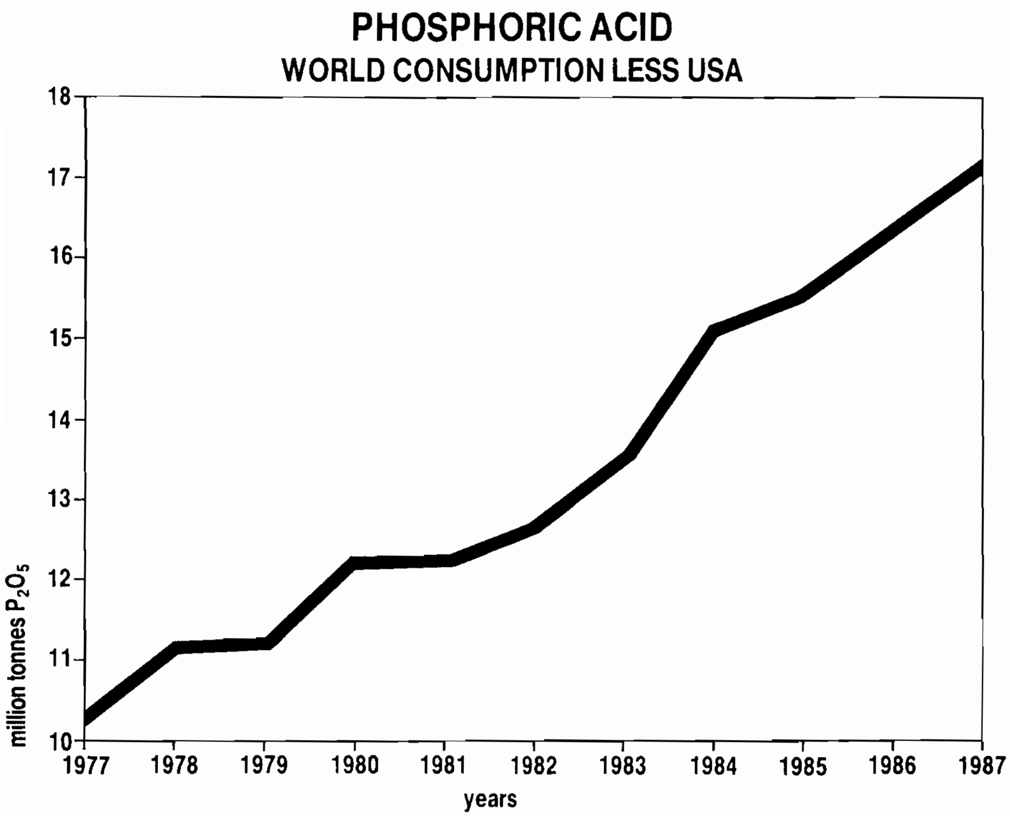


FIGURE 19

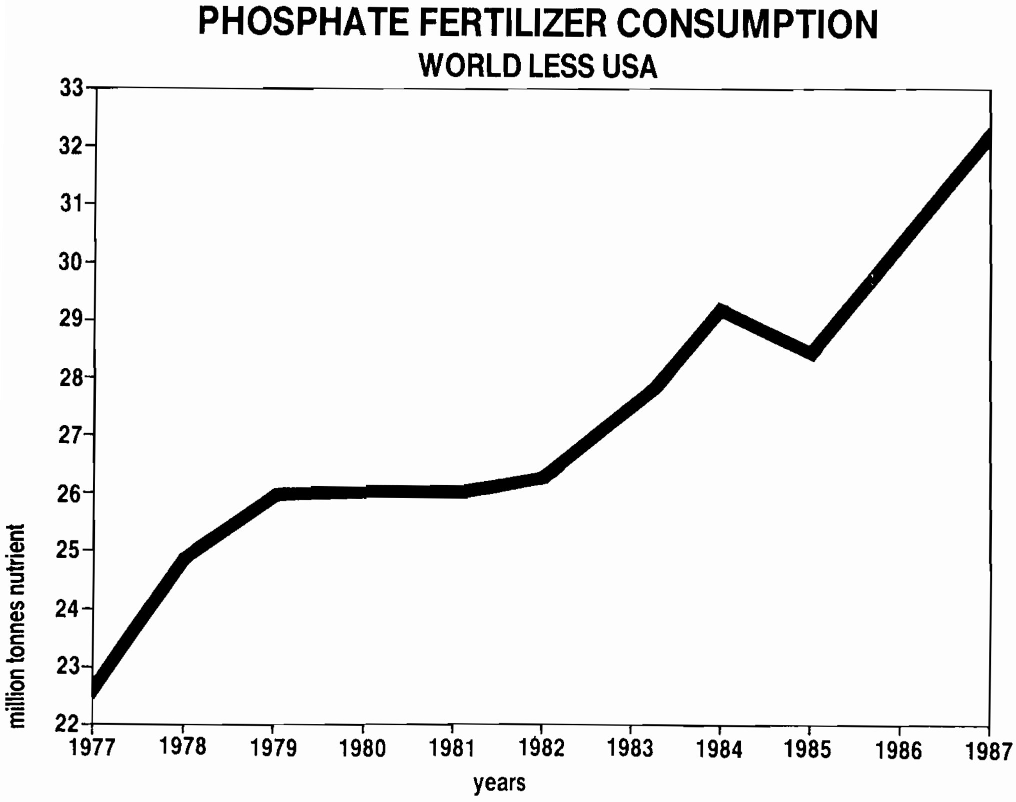
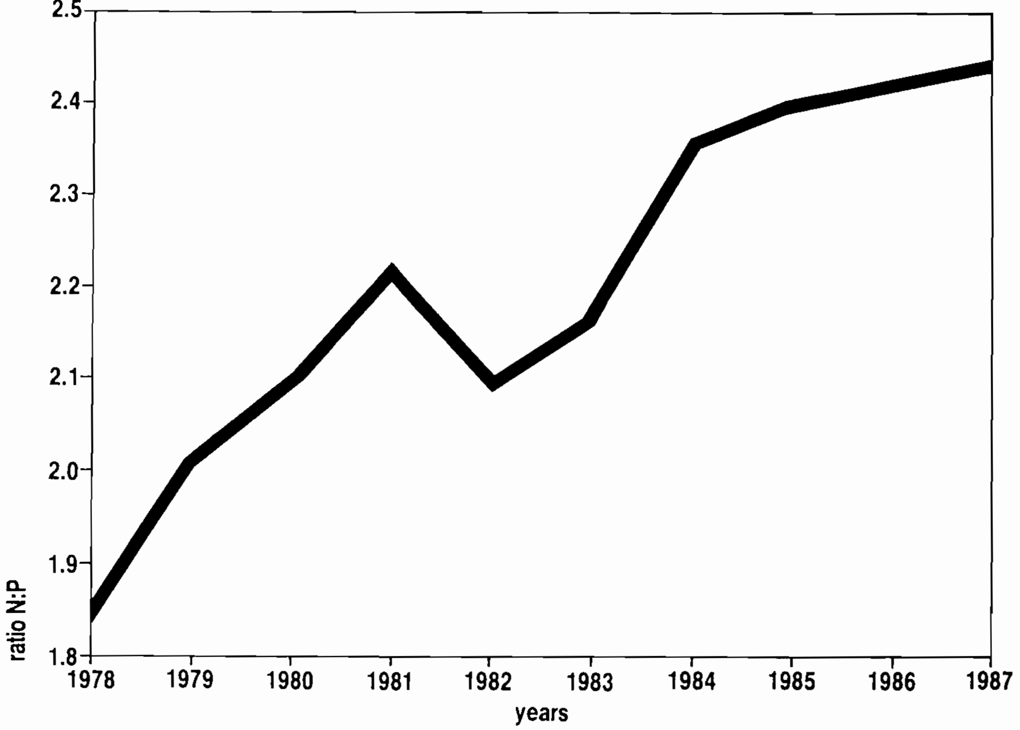
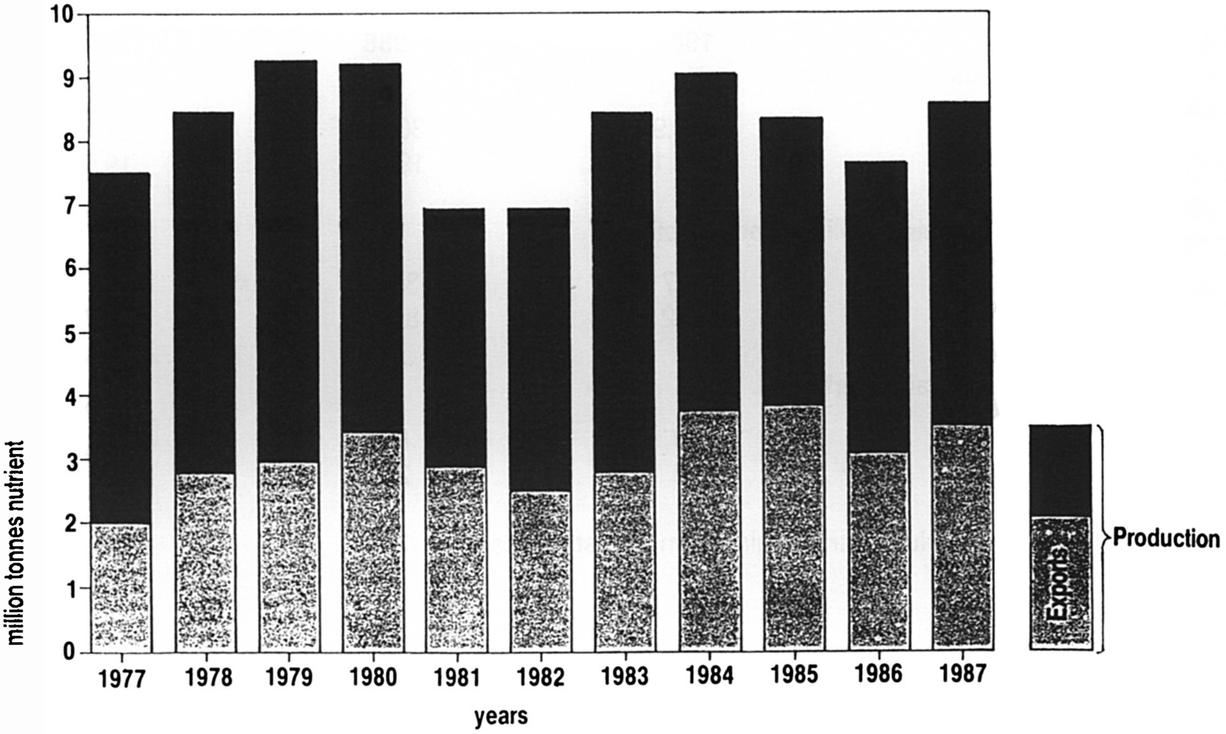


FIGURE 20



NORTH AMERICA
COMPARISON OF N AND P CONSUMPTION

FIGURE 21



NORTH AMERICA PHOSPHATE FERTILIZERS
IMPORTANCE OF EXPORTS

### FIGURE 22

## PHOSPHATE FERTILIZERS: WORLD CONSUMPTION FORECAST

(million tonnes nutrient)

| | 1987 | 1988(E) | Forecast<br>1989 | 1990 | 1991 | 1992 | 1993 |
|---|---|---|---|---|---|---|---|
| TOTAL | 36.60 | 37.88 | 38.45 | 39.18 | 39.89 | 40.53 | 41.81 |
| Change | | 1.28 | 0.57 | 0.73 | 0.71 | 0.64 | 1.28 |

**Rates of Growth**

| | |
|---|---|
| 1987-1993 | 2.24% |
| 1988-1993 | 1.99% |
| 1989-1993 | 2.12% |

### FIGURE 23

## GRAINS PRODUCTION AND PHOSPHATE FERTILIZER CONSUMPTION

(million tonnes)

| | 1985 | 1986 | 1987 |
|---|---|---|---|
| **Grains Production**[1] | | | |
| USA | 340.9 | 309.8 | 273.2 |
| USSR | 178.1 | 198.5 | 197.3 |
| **Phosphate Fertilizer Consumption** | | | |
| USA | 3.77 | 3.64 | 3.73 |
| USSR | 7.62 | 8.35 | 8.56 |
| **Ratio (grains/fertilizer)** | | | |
| USA | 90 | 85 | 73 |
| USSR | 23 | 24 | 23 |

[1] Wheat plus coarse grains from IWC statistics

# The Outlook for Potash

*Notes Prepared by C. E. Childers*
*as Presented by Leo J. Bewer*

**Potash Corporation of Saskatchewan**

We are now living in the global village that Marshall McLuhan first defined two decades ago. While our ancestors took weeks and months to reach this and other parts of North America, we can speak across the world in seconds and arrive there in hours. As someone once said, "We all came here in different ships, but we're in the same boat now."

In the fertilizer industry, and definitely in the potash industry, we are aware that rain in Ohio, drought in Iowa and student unrest in China have immediate and direct impacts on the way we do business.

Today, I would like to discuss the outlook for potash from the perspective of the potash industry in Canada in a global economy. In this context, potash is unique. On a worldwide basis, there are 69 countries which have some capability to produce nitrogen and 52 which produce phosphoric acid. There are only 13 which produce potash and 120 that consume it. This means that the world potash industry is more heavily dependent on trade than the other two major nutrients.

The dependence on international trade is vivid in Canada. In 1988, 53 percent of nitrogen sales were made to export markets. Thirteen percent of phosphate sales were exported. Exports of potash accounted for 93 percent of total sales.

In 1988, almost 19 million tonnes $K_2O$ moved in international trade. Of that, the largest single block moved from Canada to the United States. That volume—3.8 million tonnes—was larger than the total exports of any other producing country.

Sales of Canadian potash to U.S. market pale in comparison to the 7.1 million tonnes of potash consumed in the Soviet Union. We all remember the impact of the U.S. PIK program in 1982/83 when potash consumption dropped by 14 percent.

It now appears that a major drop in Soviet potash consumption may be in the offing. Prior to "perestroika," central planners dictated the volumes of potash which farming organizations used. There was also a substantial subsidy on fertilizers which meant that consumers paid only a small portion of the cost.

Now, both the consumption decision and the responsibility for payment lie in the hands of the end-users of fertilizer. Soviet press reports indicate that these developments have very quickly reduced demand for fertilizer.

At the same time, "perestroika" has presented potash producers with an incentive to produce potash. Traditional export markets, particularly within the COMECON trading bloc are limited and the Soviets are now showing signs of increased export activity in Europe, Asia, and Latin America.

So, we can now add "perestroika" to a list of factors which influence international trade in potash.

With this as background, I would like to focus on three areas: first, a comparison of world potash sales in 1980 with sales in 1988 to show how the dynamics of the world potash business have changed in this decade; second, a look at the North American situation during the 1980s; and finally, an assessment of what the future appears to hold.

Before doing that, I think it would be useful to review the 1988/89 fertilizer year in North America. Our experience, particularly with respect to the spring season, has certainly given added weight to the forecasting axiom that "random events outweigh systematic effects."

Last fall and even into the early spring of this year, most people in the fertilizer industry believed that agricultural potash consumption in North America would rise by 10 percent or more in 1988/89. This optimism was driven by the fallout of the 1988 drought which reduced production of major agricultural commodities, shrank inventories and pushed up prices.

These developments led to the prospect of up to 30 million additional planted acres in 1989 as set-aside programs were curtailed or eliminated.

What went wrong? As Yogi Berra once said, "You can observe a lot just by watching."

A key factor was uncertainty in the farm sector. Corn and soybean prices (Figure 1) fluctuated daily and weekly in response to crop prospects in South America and revised estimates of last year's production in the United States (Figure 2). The psychological benchmark prices of $3 corn and $8 beans became specks on the horizon.

This uncertainty manifested itself in lower than expected acres.

The March 31 USDA Prospective Plantings Report showed corn acreage intentions at the low end of the most pessimistic forecast. 1986 acreage of 77 million had tumbled to 66 million in 1987 and rebounded slightly to 68 million in 1988. Forecasts of planted acres in 1989 for corn averaged 76 million acres in the fall of 1988 and the spring of 1989. By March, the number had slipped to about 73 million acres. The July and August Crop Reports from USDA confirmed this low level. (Figure 3)

Soybean acreage suffered the same fate. 1986 acreage of 60 million fell to 58 million in 1987 and edged up to 59 million in 1988. Forecasts last fall pegged 1989 soybean acres at 65 million. By February, this estimate had dropped to around 62 million. USDA's survey showed that soybeans had slipped to 60 million in both August. (Figure 4)

Two other factors combined to reduce the fertilizer outlook. First, the spring came later than in the past few years. In the western cornbelt, it was late and dry and in the eastern cornbelt it was late and wet. These developments likely led to reduced application rates and to fewer fertilizer acres.

Another factor which was almost lost in the optimism of last fall was unusually high dealer inventory, particularly of phosphates and potash. This material moved to field application before sales from producers and represented the loss of about one month's anticipated sales.

While consumption data will not be finalized until late in the year, it is likely the U.S. and Canadian agricultural consumption of potash was about equal to 1987/88. We know that North American producers' sales in the continent were down 4.8%. This provides us with one bit of good news—that dealer inventories are low. For potash it appears that July 1, 1989 dealer inventories were at "normal levels"—about half of what they had been in the previous three years.

Before turning to the prospects for 1989/90, I would like to move to something we know for sure. That is the history of North American and world potash sales since 1980. This bit of history is important in that it sets the stage for developments in the 1990s. (Figure 5)

In the case of North American potash sales, between 1980 and 1988 two features stand out. First, the level of sales has fluctuated from year to year but the trend since 1980 has been down. Second, there are more suppliers in 1988 than in 1980—largely with the addition of New Brunswick producers but also with the sustained presence of offshore producers. (Figure 6)

On a world basis, the Soviet Union and Canada continue to be the dominant suppliers of potash. (Figure 7) Eastern and Western Europe and North America continue to dominate potash consumption. (Figure 8) As a group, they consume about three-quarters of all sales. Latin America's share has remained at 7 percent while Asia's share has risen from 11 percent to 16 percent. (Figure 9)

The growth in world potash sales has been supplied primarily from the Soviet Union. Canada's share of increased sales was second to the USSR but only slightly ahead of Jordan. (Figure 10)

Canada's share of increased sales contrasts sharply with its share of increased productive capacity—an increase in sales of just under one million tonnes $K_2O$ compared with an increase of about 4 million tonnes of productive capacity.

The imbalance in Canada's share of sales versus its share of productive capacity can be explained by looking at individual market areas. (Figure 11)

In Eastern Europe, the presence of local suppliers and the existence of the Comecon trading block effectively excludes almost all producers except those in the USSR and East Germany. The increase in sales between 1980 and 1988 went almost entirely to the USSR—a total of 2.5 million tonnes. (Figure 12)

In Western Europe, indigenous production and logistics restricts this market primarily to Western European producers. Producers in West Germany, France, East Germany and the Soviet Union saw their tonnage drop while Israeli, Jordanian and Canadian tonnage rose. Canada's presence here—with almost half a million tonnes $K_2O$—is largely supplied by New Brunswick producers. (Figure 13)

In North America, Canadian and American production dominates but European, Israeli and Soviet product continues to play an important role in some markets.

There are two key consuming areas where there is minimal production of potash and where almost all world producers participate. (Figure 14)

Asia is one such market. Canada has a dominant position here. Canadian producers represent 60 percent of the increased sales between 1980 and 1988. European and Jordanian product is also a factor. Almost all of Jordan's production which came on stream in this decade was sold in Asia. Canada's position in this market is due in no small part to the market development activities undertaken jointly by Canpotex, Potash & Phosphate Institute and the Canadian International Development Agency. (Figure 15)

Latin America is also an area where most producers compete. Canada's presence is the largest but is less dominant than in Asia. The East German presence is largely tied to bilateral trade arrangements with Brazil. The USSR is again a significant factor in this market. (Figure 16)

If we look at potash markets where Canada can compete from a logistics standpoint and without any barriers to trade, we look at "available potash export demand" in Asia, Latin America, Africa, and Oceania. (Figure 17)

In that arena, Canadian producers clearly stand out in terms of a rising share of that business in both absolute and percentage terms. (Figure 18)

The poet John Donne said that no man is an island. That remark certainly has relevance to the world potash industry and it can be most vividly seen in price trends. Here, we have looked at the domestic price of coarse product and the offshore prices of all grade f.o.b. Saskatchewan in constant 1980 dollars. Both North American prices and offshore prices tend to move in the same general direction over time. It cannot be said that U.S. prices tend to dominate the world market but neither offshore prices nor U.S. prices can move without having some effect on the other. It is also interesting to observe that in constant dollar terms, we have not yet returned to the price levels of nine years ago.

The bottom line is that while the North American market is of considerable importance to Canadian potash producers, markets in Asia and Latin America are crucial as well. Like North America, they are accessible to Canadian producers and, more importantly, they are markets which have been growing and which show signs of continued growth. While consumption in these areas is important, so is consumption in areas where we do not compete. For example, consumption in Europe or the USSR determines how much those areas will attempt to market in Asia or Latin America.

As a general statement, four things contribute to demand for potash or any other nutrient.

The first is population growth. While an additional person born does not translate into an automatic increase in food production, that additional demand, whether completely satisfied or not, places pressure on families and nations to feed him or her. It should be of considerable concern to all of us that, according to the World Food Council, less food is being produced per person in the low income food importing countries of Africa, the Near East, Latin America and Oceania than there was almost 20 years ago. This is because population growth has exceeded growth in food production. (Figure 19)

While world population growth is declining from the 1.9 percent annually in the past 37 years, present world population of 5.2 billion people is expected to rise to 5.7 billion by 1995. Latin America and Africa are expected to rise faster than other regions. Latin America is expected to rise from 338 to 382 million by 1995 and Africa, from 524 to 650 million people.

Asia's population is forecast to grow at the world average but in absolute terms will rise from 2.6 billion to 2.9 billion between now and 1995.

The population of Eastern and Western Europe is expected to rise only marginally from its present level of 465 million. North American population is expected to rise by 26 million to 386 million people by the mid 1990's.

The second contributing factor to fertilizer demand is acreage. (Figure 20)

For the world as a whole, a study done in 1988 by the WEFA Group for the U.S. Bureau of Mines forecast harvested acreage to rise from 1.885 billion acres in 1989 to 1.930 billion acres in 1995—an increase of just over 2 percent. That net 45 million acre increase was driven by a rather bullish outlook for U.S. acreage which we may not see. However, Latin America, Asia, Africa and Oceania were forecast to show increases, while Western and Eastern Europe and the USSR were all showing declines.

The third element which drives fertilizer demand is the ability to pay for it. This is usually measured by economic growth. (Figure 21)

Using real growth in Gross Domestic Product over the next five years, the world economy is expected to grow at 2.9-3.3 percent annually, with Organization for Economic Cooperation and Development countries ranging from 2.2 to 2.9 percent and developing countries ranging from 3.9 to 4.5 percent. The Pacific Basin countries (Malaysia, Indonesia, etc.) show the highest rates at 4.7 to 6.1 percent.

The final element in determining potash demand is the state of agricultural development in industrial countries. For example, on a worldwide basis, nitrogen/potash ratios are about three to one; in China the ratio is about 15 to one. Clearly, as countries such as China become self-sufficient in cereal production greater emphasis will be placed on oil and protein crops which have higher potash requirements.

Agronomic programs sponsored by Potash & Phosphate Institute and Canpotex have demonstrated positive responses in this area particularly in China.

To put together a kind of report card on consuming areas based on these four factors, there is a lot of conflicting information. In a nutshell, areas where there is a large population and acreage base and, most importantly economic growth, are the most promising for increases in fertilizer demand. Asia and Latin America show up as areas where potash demand will likely increase.

The annual forecast of the World Bank and Food and Agriculture Organization in June of this year reflects this report card. It shows world potash fertilizer demand rising from 27.7 million tonnes $K_2O$ in 1989 to 30.1 million in 1994 and 32.4 million in 1999. This equates to a 1.5 percent annual increase. (Figure 22)

The variance among regions is significant. North American growth is forecast at 1.2 percent from 1988 to 1999. Western European demand is forecast to slowly decline through to the 1990s.

In developing market economies, annual growth rates in excess of 3 percent are projected. African growth is pegged at over 5 percent albeit with small base tonnage. Latin American growth is forecast at 2.3 percent to 1999—a good deal lower than previous forecasts.

The Near East, Socialist Asia and the Far East are the most robust markets with annual growth of 5-8 percent in the 1990s. While Eastern Europe is forecast to grow very slowly on a percentage basis, in absolute terms, a rise of over one million tonnes is forecast.

This relatively modest overall growth outlook means the continuation of surplus productive capacity through the 1990s. The World Bank is forecasting that world capacity will rise from 37.5 million tonnes $K_2O$ in 1988/89 to 38.1 million tonnes in 1993/94. Factoring in industrial sales and losses, this still leaves over 5.5 million tonnes of world surplus capacity by 1994. (Figure 23)

Turning back to the North American market and the prospects for next year, there appear to be signs of optimism. I am sure you have heard this before. It has the familiar ring of, "the cheque's in the mail." But let us look at some of the things that are going on now.

First, the 1989 harvest is moving along smoothly and harvest levels are moving closer to normal, with the notable exception of cotton. Average yields are being reported and this will not lead to excess inventories.

This should lead to planted acres next spring of about the same magnitude as this year—although soybeans will likely be down and wheat up.

The drought of 1988 resulted in residual nutrients in the ground. The dry conditions in the western corn belt and the wet conditions in the eastern corn belt led to lower application rates. Next year, it is likely that we will see a return to trend yields.

The other bit of good news for fertilizer producers is that mid-summer dealer inventories were low. This means that fertilizer producers will not have to compete with product they have already sold.

We can expect North American potash consumption to rise in 1989/90—possibly as much as 4 percent over 1988/89 if current estimates of that year's consumption prove accurate.

Potash sales can be expected to rise at a faster rate than consumption with low dealer inventory. The impact of rising acres in 1989 will therefore be felt in 1990—one year later than most of us thought. This is good news—not as good as the levels of the early 1980s but good news nonetheless.

For potash and other products competing in world markets, we think we know what is going on to determine sales in a given period but we cannot determine with much precision a whole variety of economic, political and climatic factors which can dramatically change the way we do business next month or next year.

You may have heard the story about the two economists who went moose hunting. After spotting a moose, the first economist fired 20 feet short of the mark. The second economist took aim and overshot his target by 20 feet. But they both jumped for joy when they realized that on average, they killed the moose.

In the final analysis, the way we handle short term impacts determines our long term success. That success needs to be anchored to a long term view of our role in global markets. For us at PCS and indeed for the Canadian potash industry, a key element of that long term view is that we have a product that is essential to the production of food for a world population that will continue to rise over the foreseeable future. We can produce potash efficiently, market it skillfully and deliver it to global markets that need it.

**FIGURE 1**

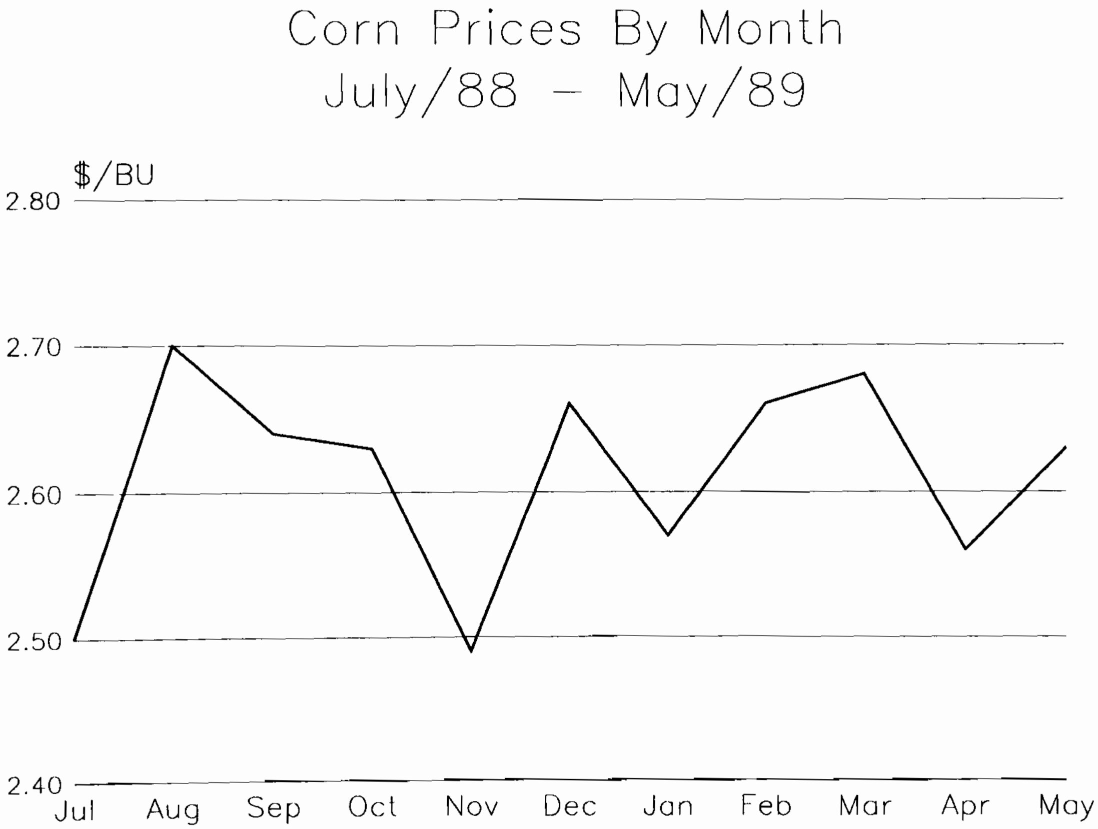


**FIGURE 2**

Soybean Prices By Month
July/88 – May/89

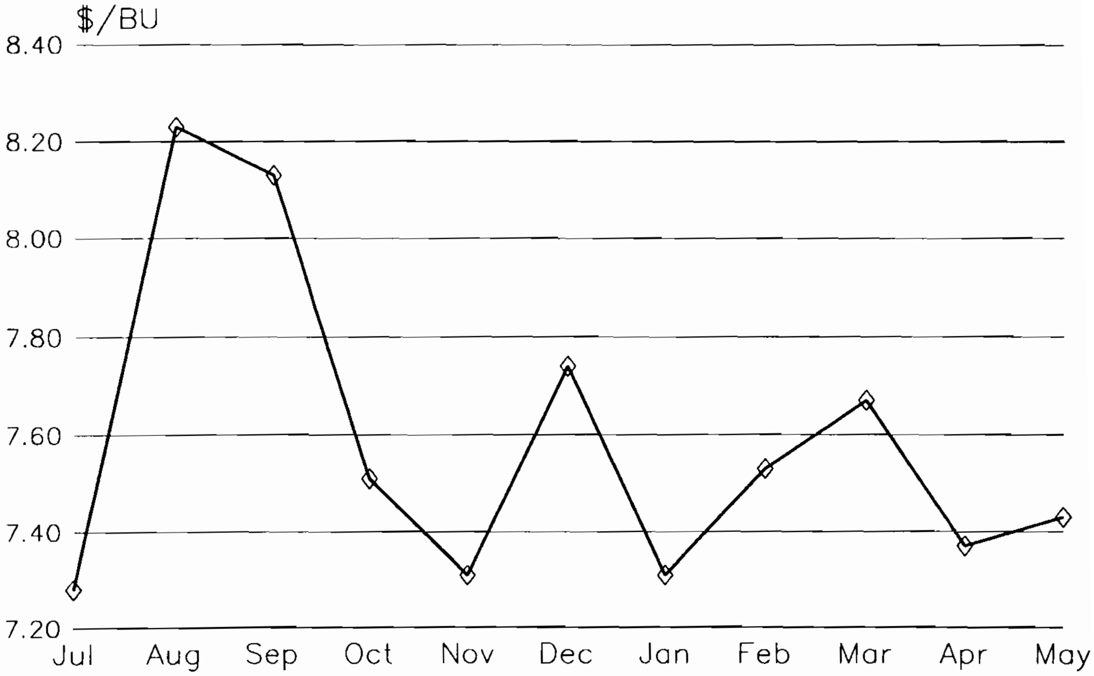
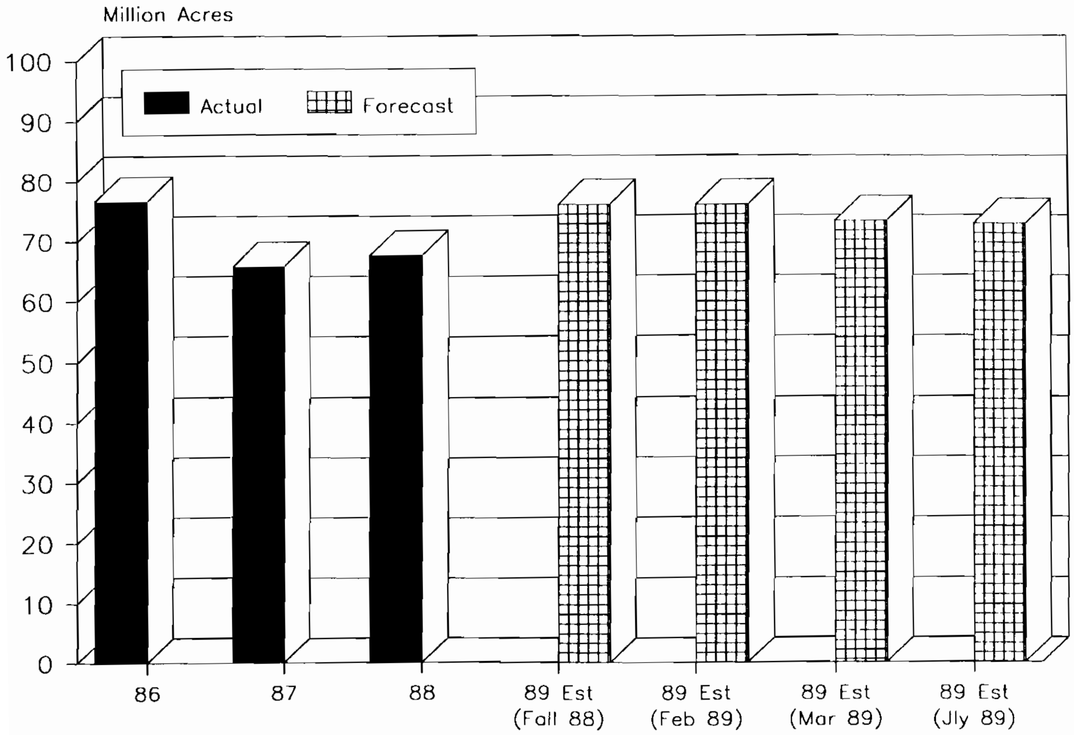
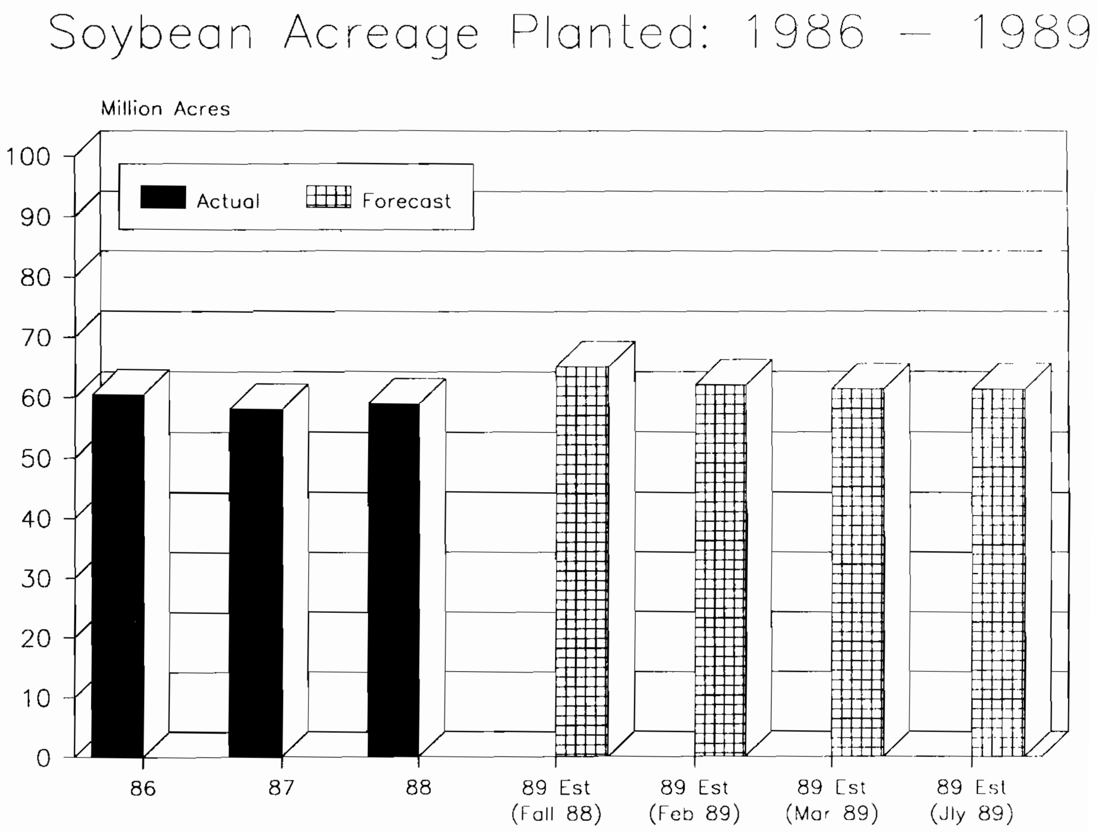


**FIGURE 3**

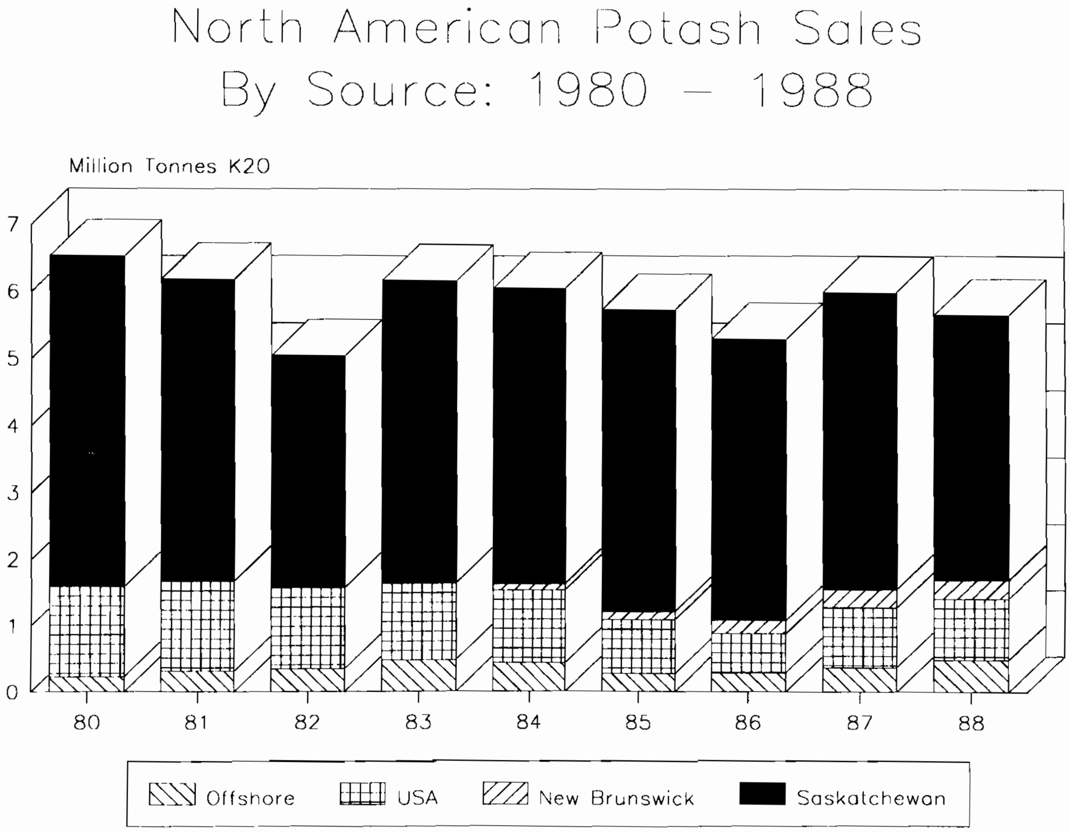
Corn Acreage Planted: 1986 – 1989



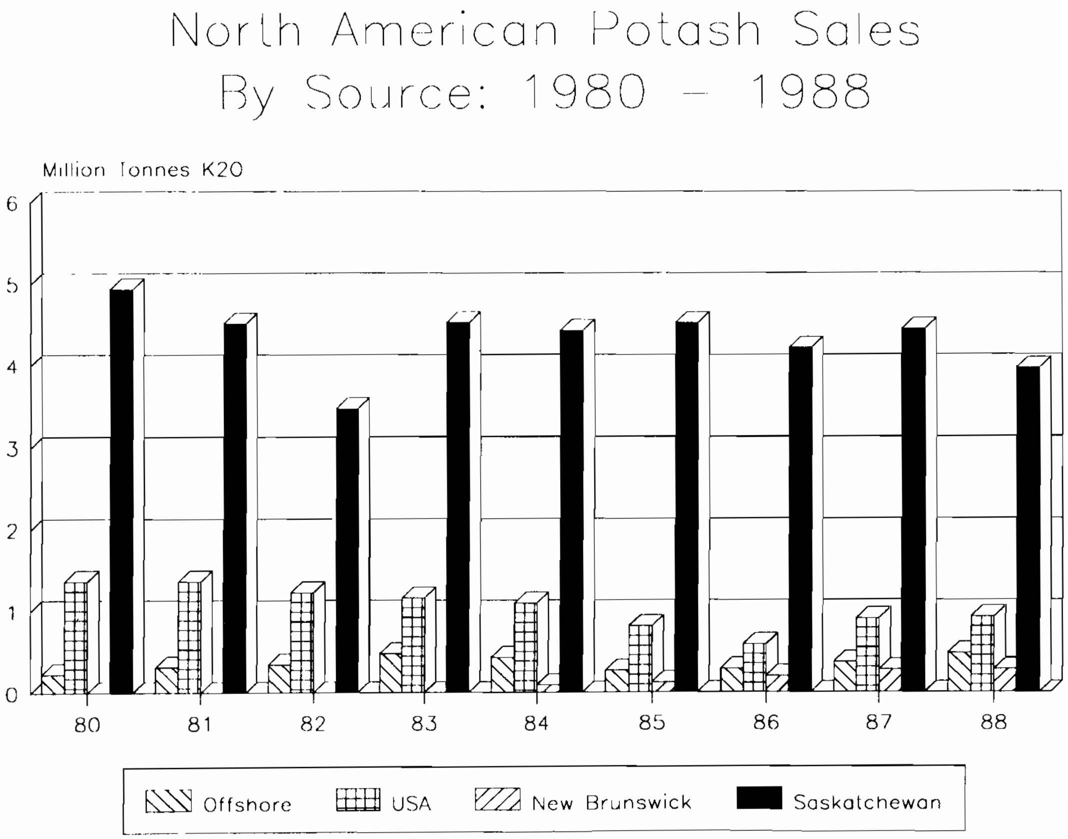
## FIGURE 4



## FIGURE 5



## FIGURE 6



## FIGURE 7

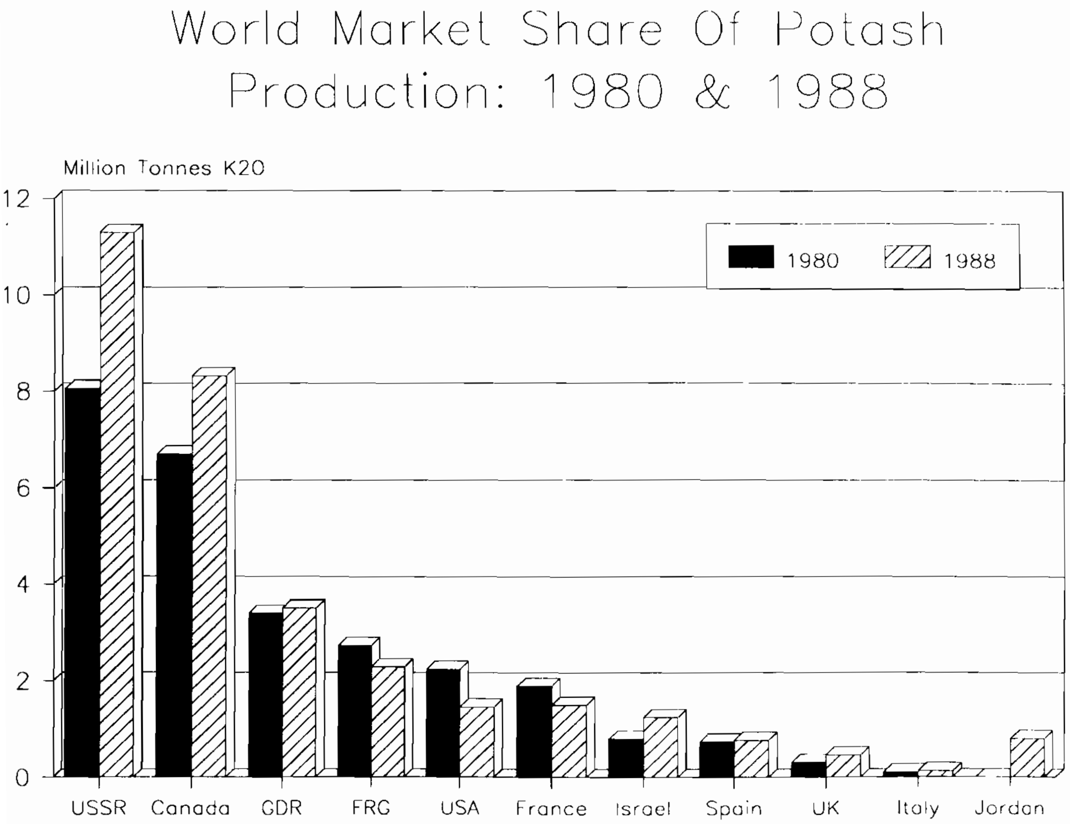


**FIGURE 8**

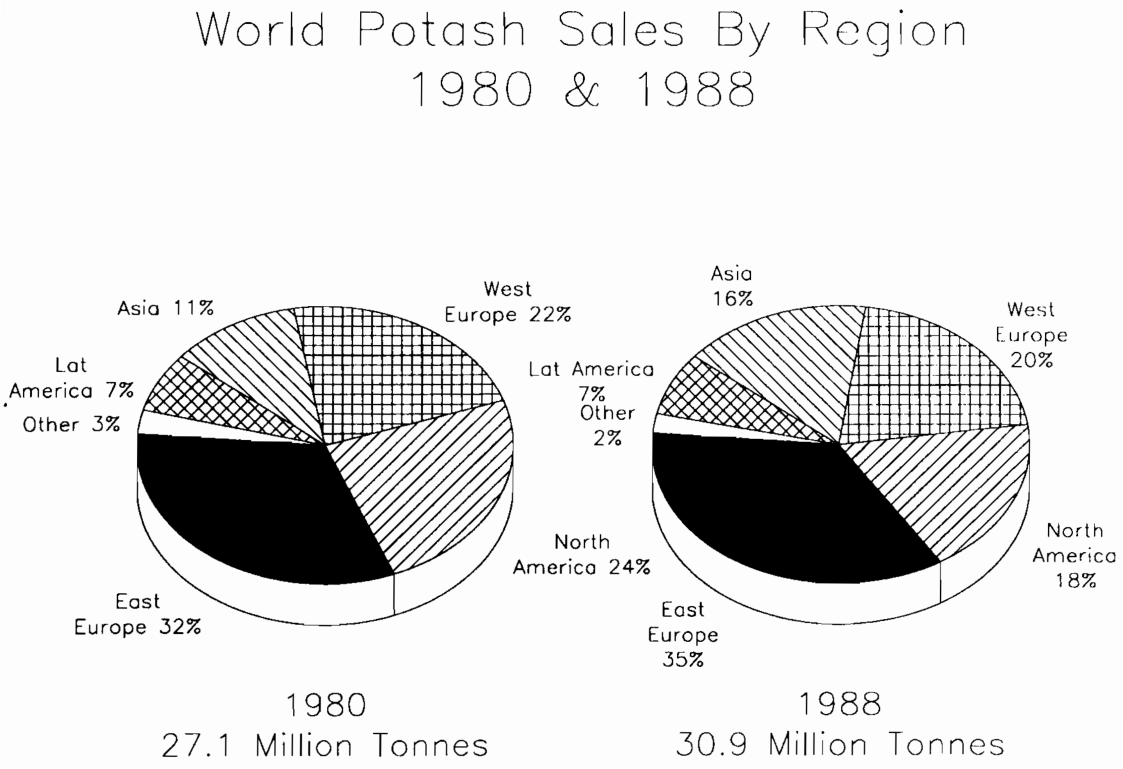


**FIGURE 9**

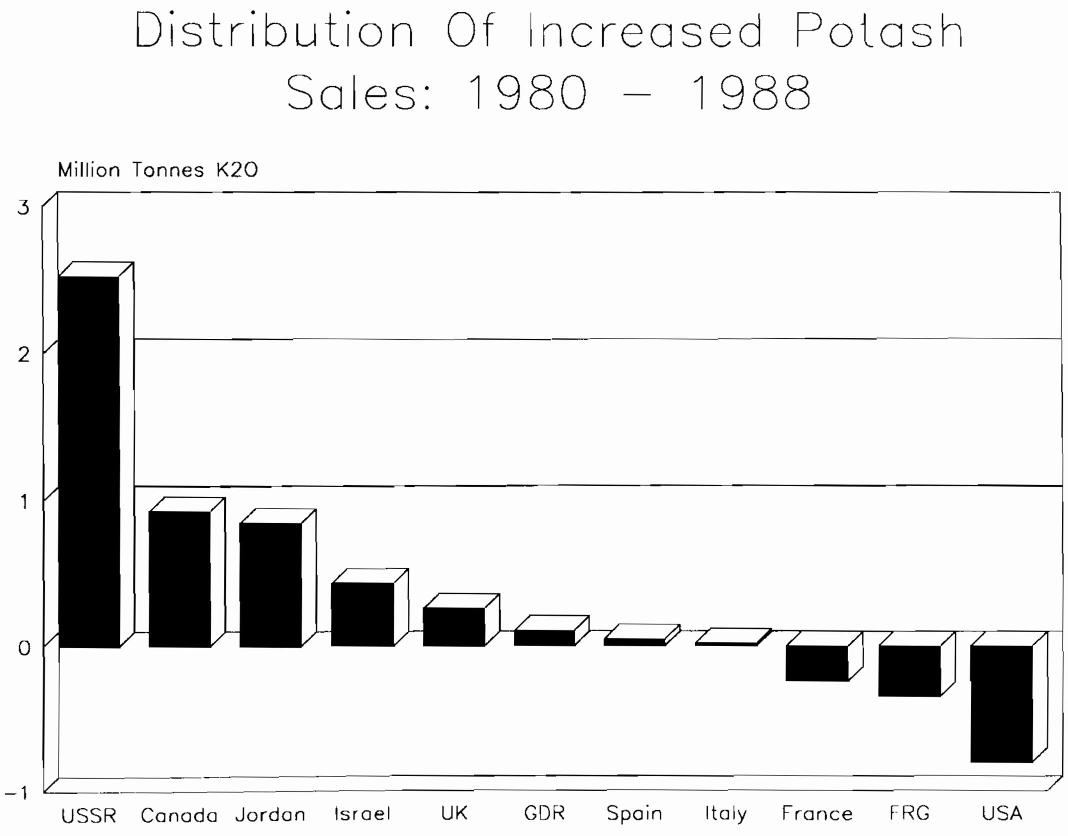


**FIGURE 10**

Distribution Of Increased Potash Productive Capacity: 1980 – 1988

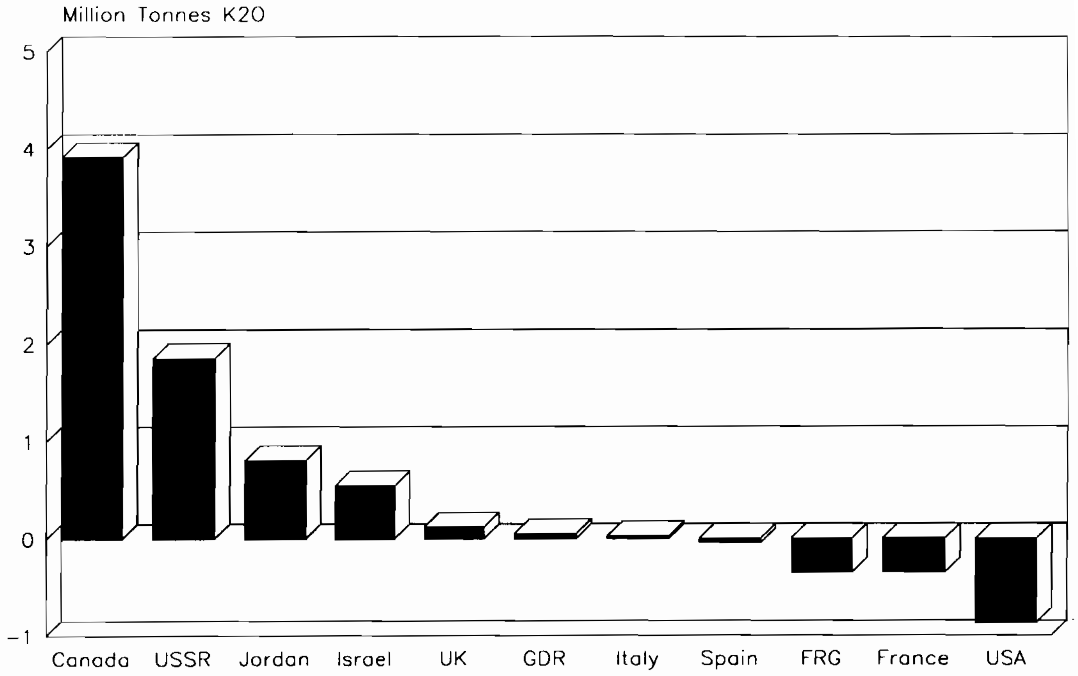


**FIGURE 11**

Share Of Potash Sales In East Europe 1980 & 1988

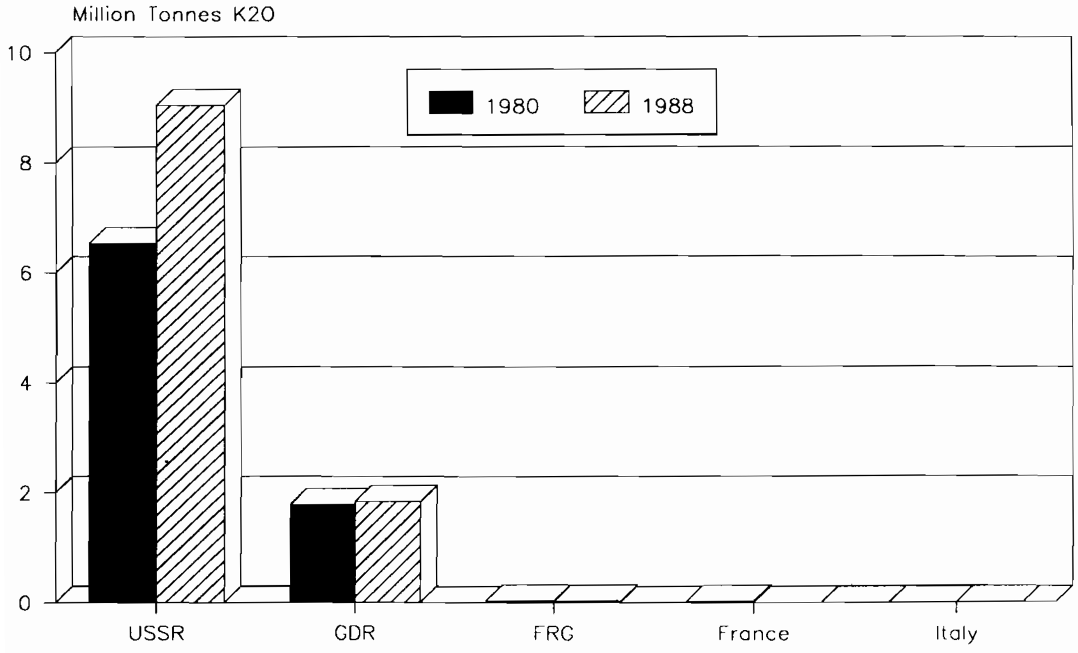


**FIGURE 12**

Share Of Potash Sales In West Europe 1980 & 1988

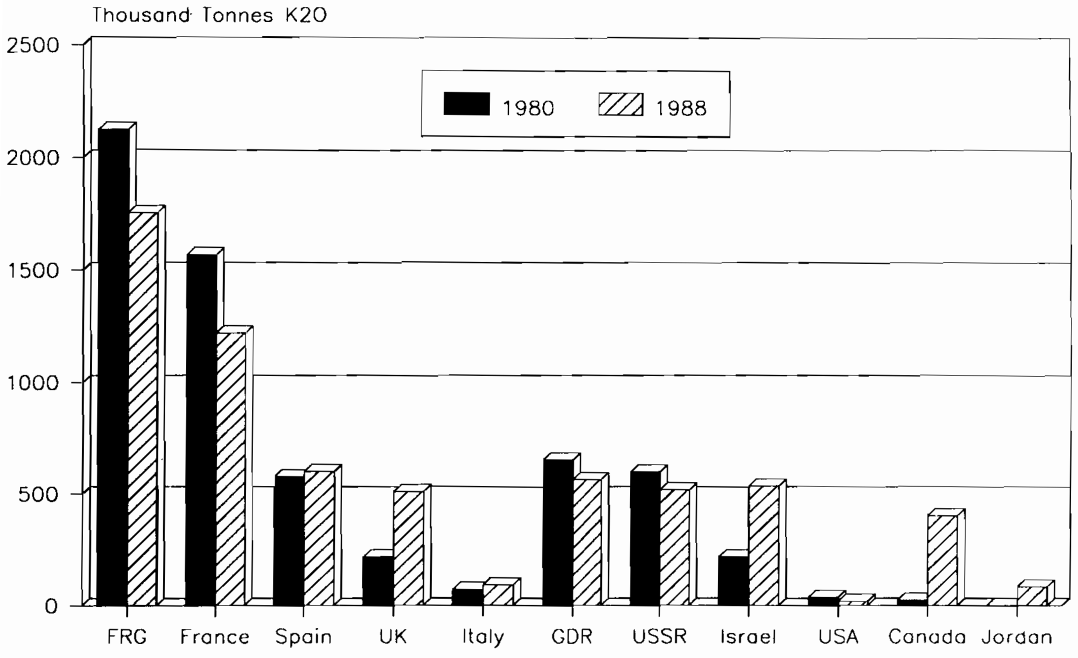
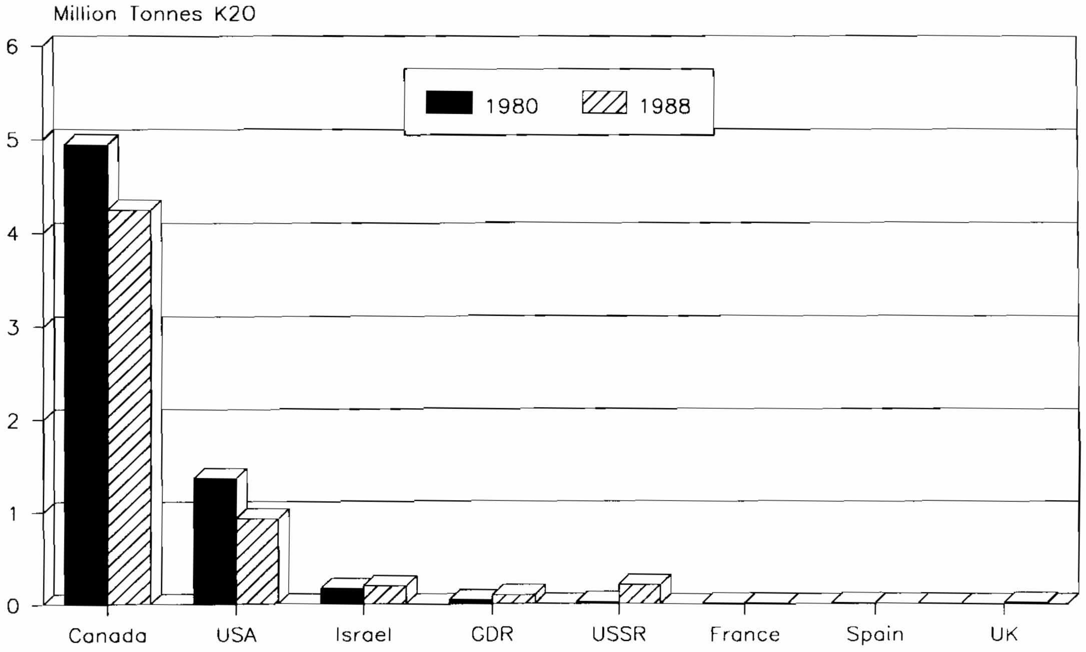
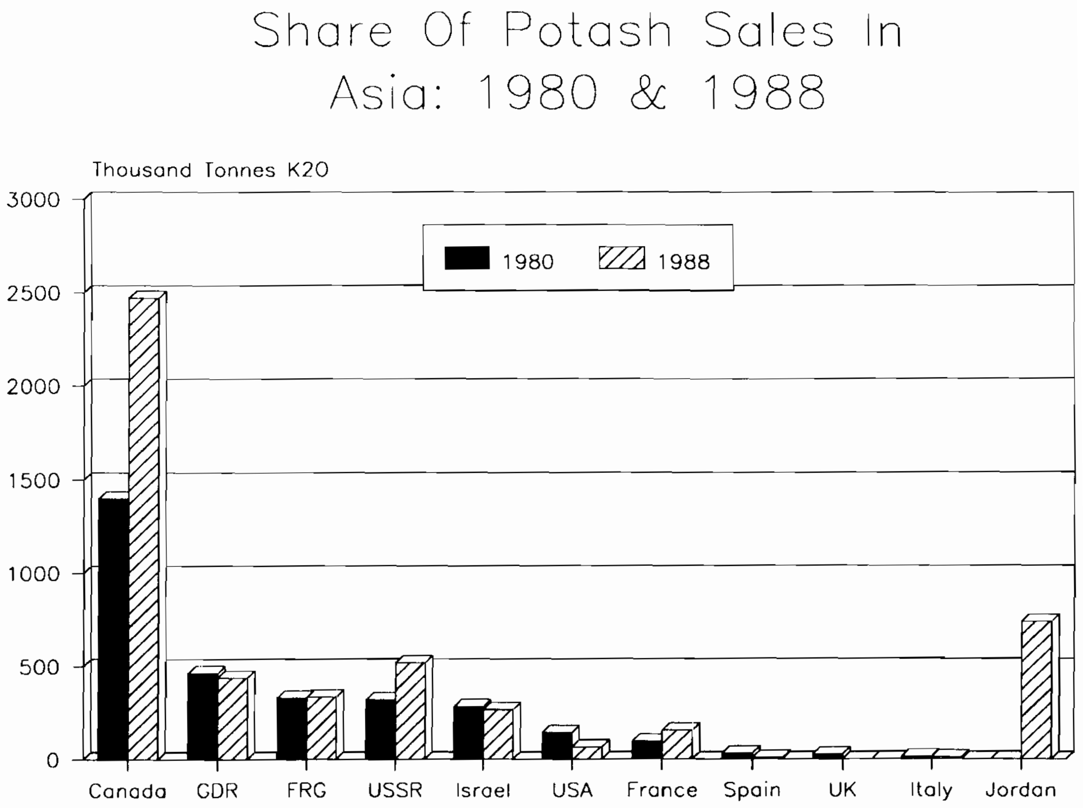


**FIGURE 13**

Share Of Potash Sales In North America: 1980 & 1988



## FIGURE 14



## FIGURE 15

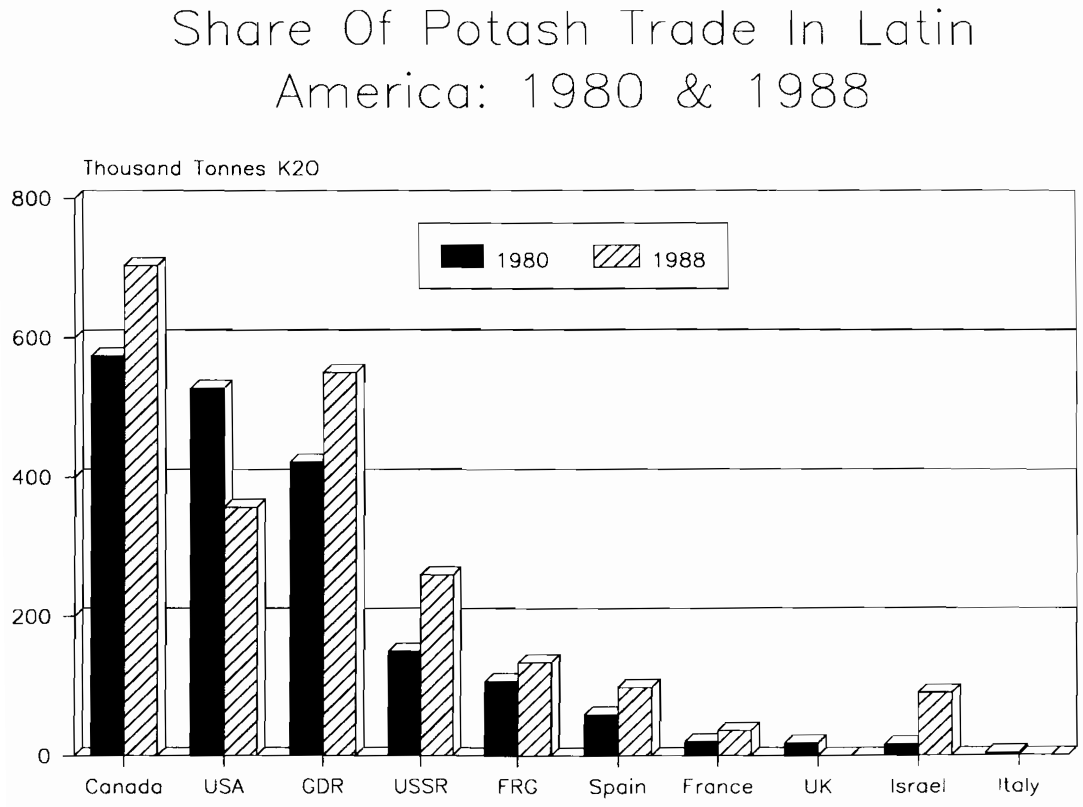
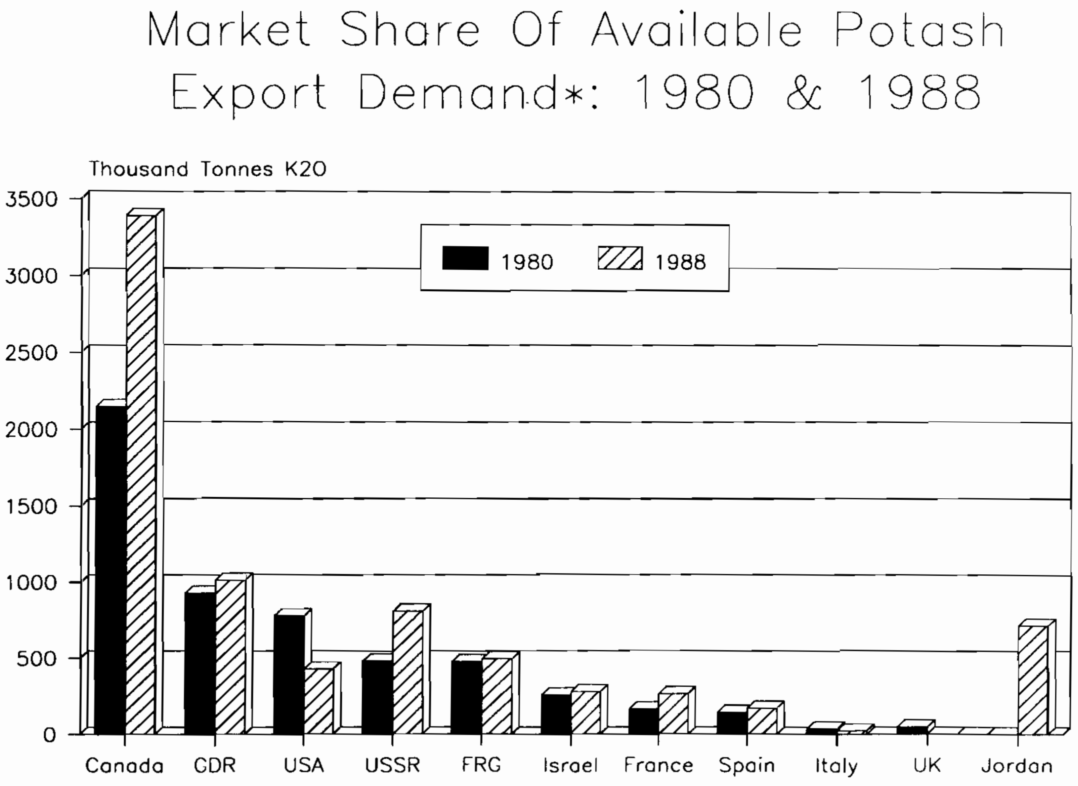
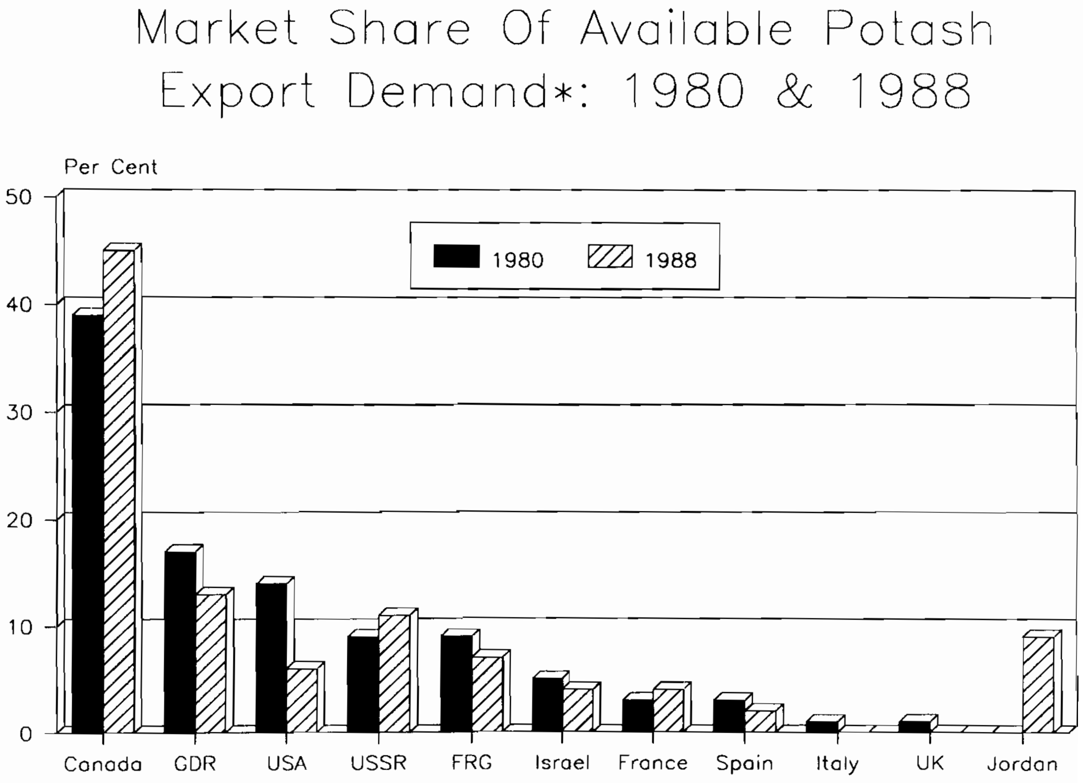


**FIGURE 16**



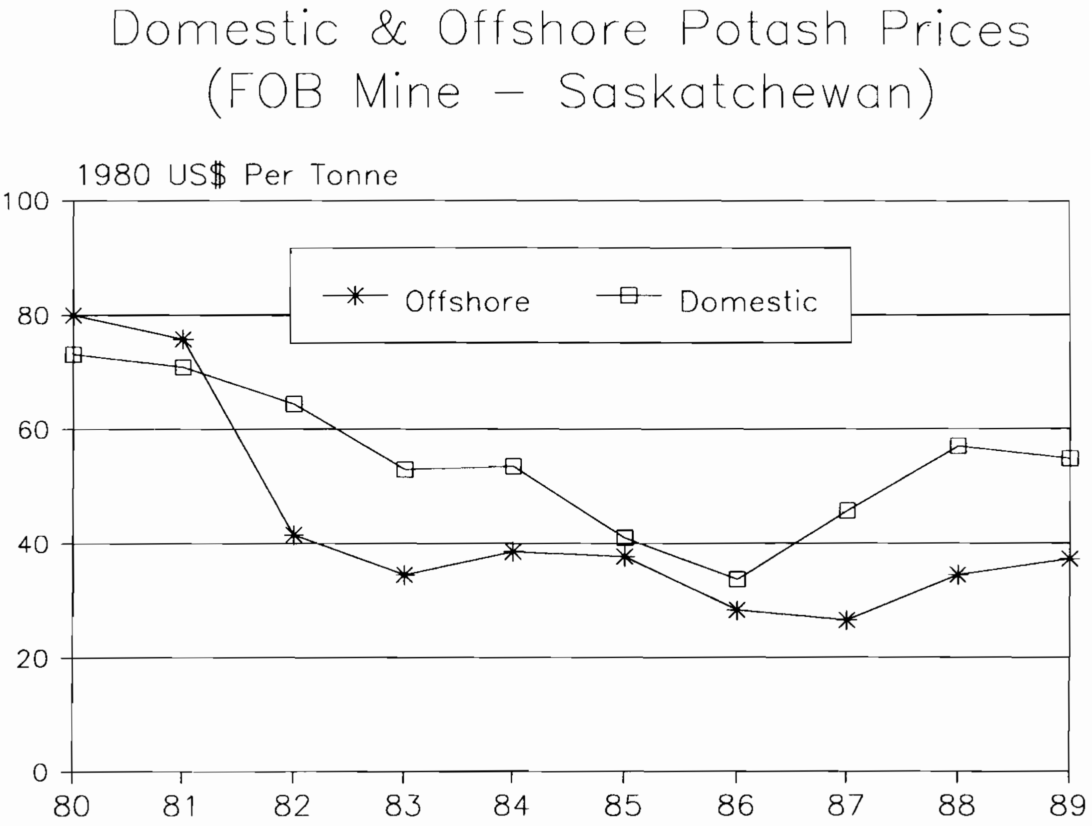
*Asia, Africa,Latin
America & Oceania

**FIGURE 17**



*Asia, Africa,Latin
America & Oceania

## FIGURE 18



## FIGURE 19

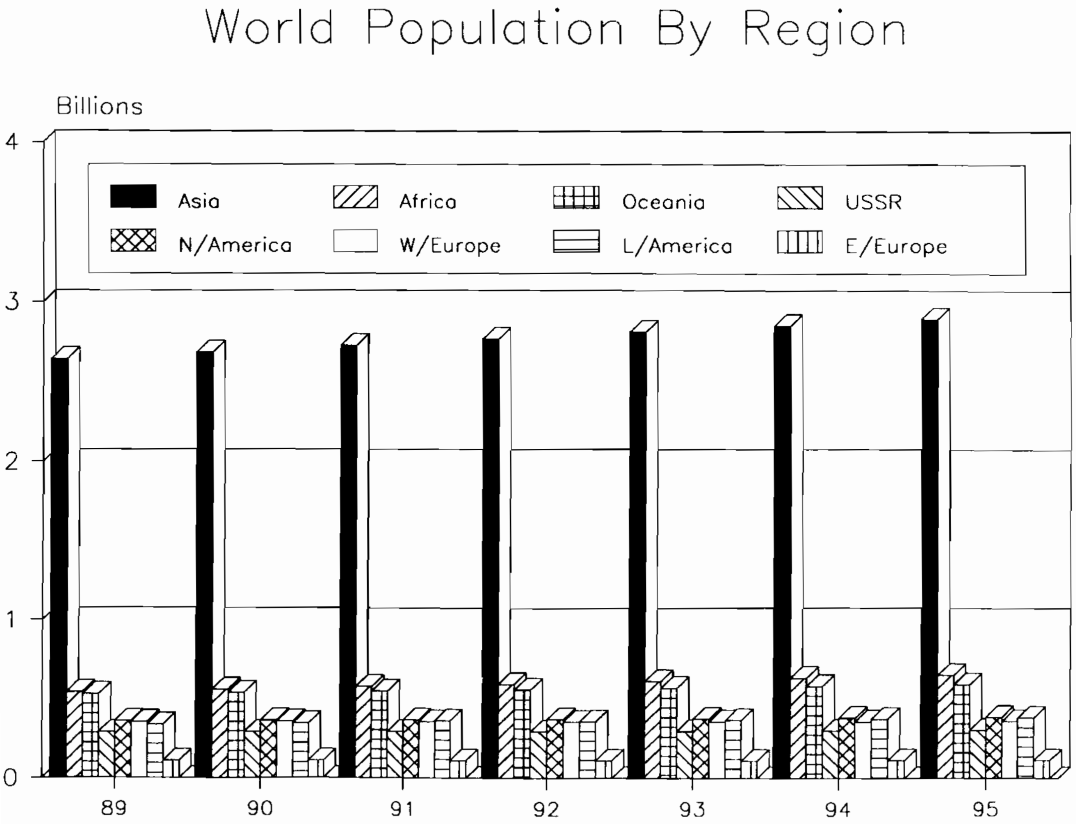


**FIGURE 20**

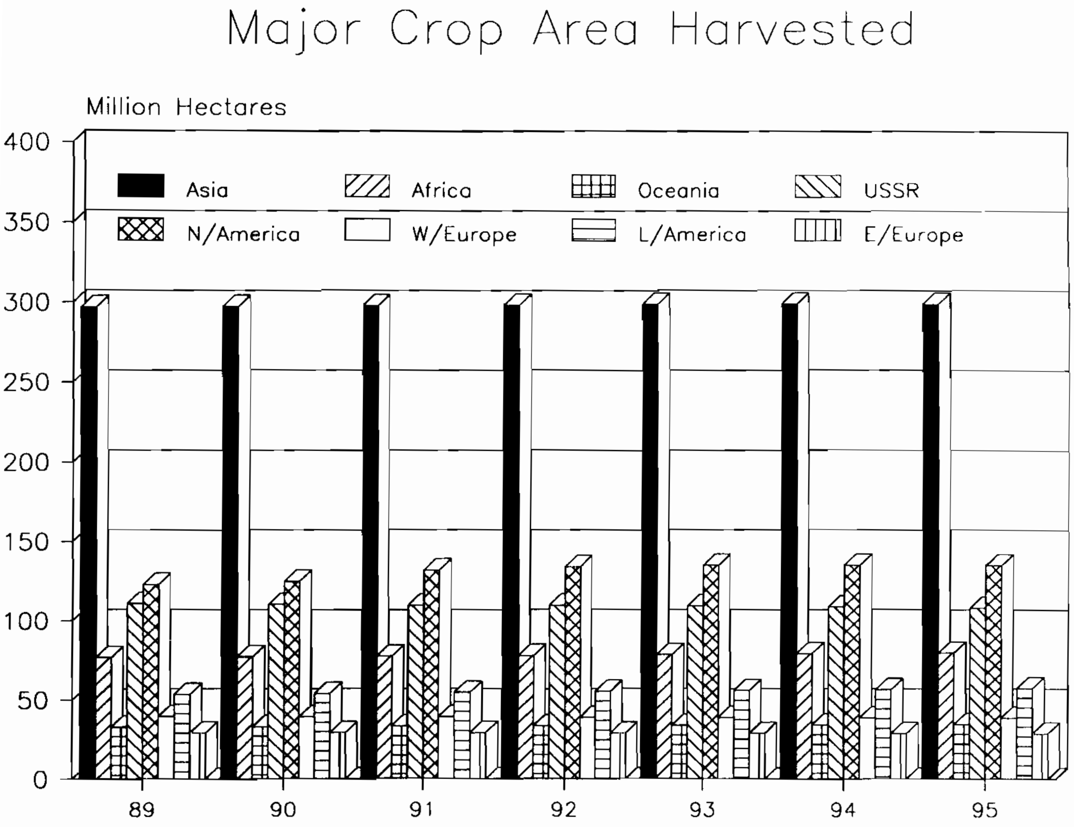


**FIGURE 21**

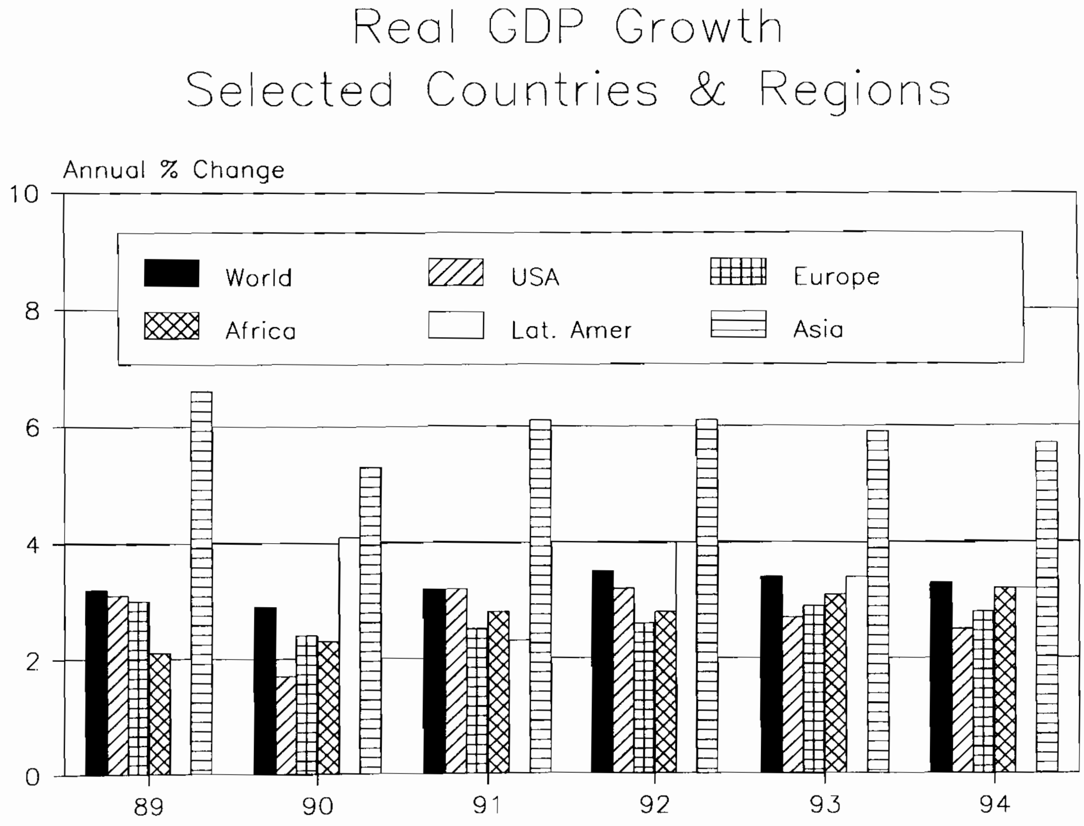


**FIGURE 22**

Potash Fertilizer Demand
1987/88 – 1998/99

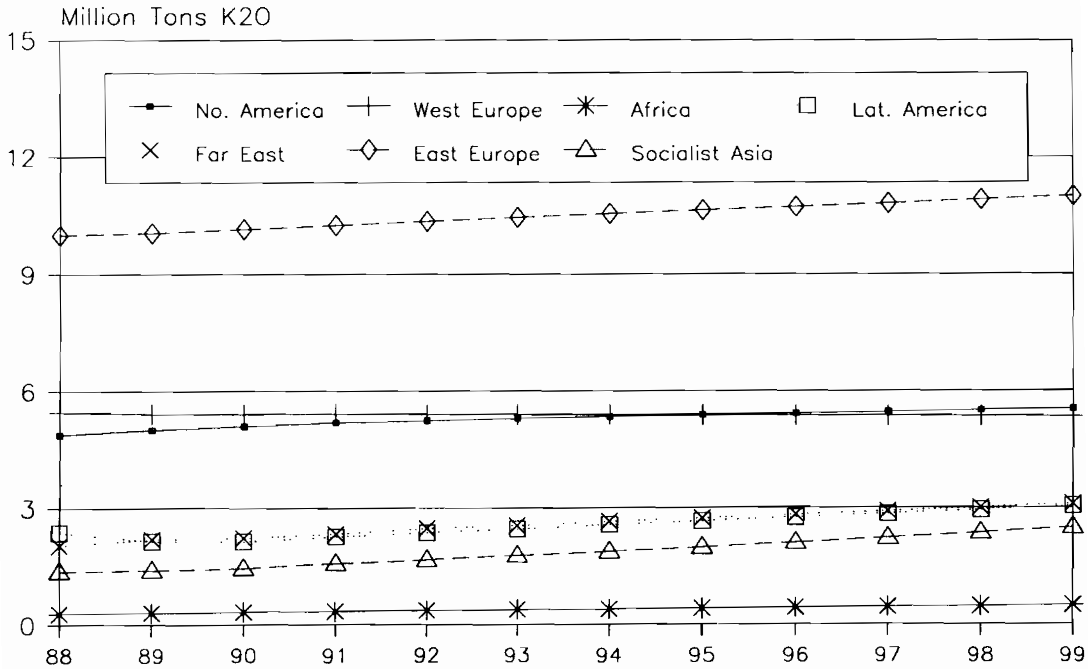
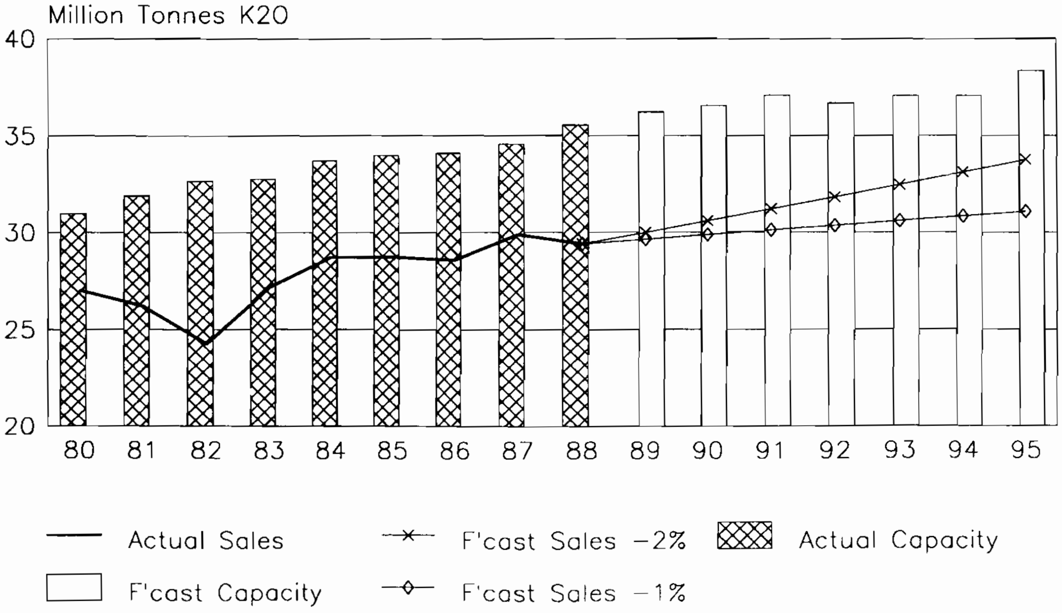


**FIGURE 23**

Actual & Forecast Potash Sales
And Productive Capacity: 1980 – 1995



# Global Fertilizer Perspective, 1960-95

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## *INTRODUCTION*

In the 1980s, the global fertilizer sector witnessed several changes: First, there was a slowdown in growth of fertilizer use, and consequently per capita fertilizer use stagnated. Second, fertilizer use fluctuated from one year to another; it decreased on three occasions (1983, 1984, and 1986) during the 1980-87 period as against once (1975) during the 1960-80 period. Third, in spite of low fertilizer prices, fertilizer use decreased. Fourth, because of low and unremunerative prices, many fertilizer plants were closed and several were idled. Fifth, the traditionally dominant users and producers of fertilizers, namely, North America and Western Europe, experienced a decrease in their shares in global fertilizer use and production.

These changes indicate that the structure of the global fertilizer sector was changing rapidly in the 1980s. Hence, a comprehensive and long-run analysis of the factors affecting fertilizer use and production at the global and the regional levels was pursued to unravel the dynamics of growth and structural change. The findings of that analysis were incorporated in developing the future outlook for fertilizer demand, supply, and prices.

As the growth in fertilizer use has played a key role in promoting growth in food production, a stagnation in per capita fertilizer use during the 1980s also necessitated an analysis of the impact of the projected growth in fertilizer use on food security in Asia, Africa, and Latin America.

The detailed results of the analysis in these three areas, namely, historical trends, future outlook, and food security and fertilizer use, are contained in the main volume of the study, entitled *Global Fertilizer Perspective, 1960-95: The Dynamics of Growth and Structural Change* (IFDC Publication T-34), and are summarized in the Executive Summary (IFDC Publication T-35).

This paper summarizes important themes and conclusions of the study dealing with historical trends and future outlook.[1]

## Trends In Fertilizer Consumption, 1960-87

### *GLOBAL TRENDS*

Total fertilizer use increased from 27.4 million tons in 1960 to 111.1 million tons in 1980 and 132.3 million tons in 1987. N, $P_2O_5$, and $K_2O$ use increased from 9.5, 9.8, and 8.1 million tons in 1960 to 57.2, 29.9, and 24.0 million tons in 1980 and 72.4, 33.8, and 26.1 million tons in 1987 (Table 1 and Figure 1).

The growth in fertilizer use slowed during the 1980s compared with the 1970s and the 1960s. Total fertilizer use grew at 2.6% per annum during the 1980-87 period. This growth rate was less than one-half of the annual growth in the 1970s and less than one-third of that in the 1960s; it was also less than two-thirds of the projected annual growth for the 1980s (Figure 2).

In addition to the slowdown in growth, fertilizer use fluctuated from one year to another. During the 1980-87 period, total fertilizer use decreased on three occasions (1983, 1984, and 1986) as against once (1975) during the 1960-80 period.

The slow growth in total fertilizer use produced near stagnation in per capita fertilizer use. During the 1960-80 period, per capita fertilizer use increased from 9 kg in 1960 to 26 kg in 1980, whereas during the 1980s it hardly changed (Figure 3).

Although several factors affected fertilizer use, the following factors seem to have played a dominant role in causing slowdown and fluctuations in fertilizer use in the 1980s:

1. Macroeconomic changes—debt crises, foreign exchange shortages, and balance of payment difficulties, which caused many countries to reduce fertilizer imports and, therefore, fertilizer use.
2. Microeconomic changes—low crop prices in North America, Western Europe, and Oceania.
3. Policy changes—acreage reduction programs, especially in North America, and subsidy removal programs in many developing countries.
4. Climatic changes—droughts and inadequate rainfall in many parts of the world.
5. Agronomic factors—residual phosphorus in the soil.

### *NUTRIENTWISE GROWTH*

Although all three nutrients experienced slowdown in use growth, phosphate and potash use experienced sharp declines in their annual growth rates. Compared with more than 4% annual growth in the 1970s, potash and phosphate use grew at less than 2% per annum during the 1980s. Economic (low crop prices and foreign exchange shortages) and agronomic

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[1] Copies of the main volume and the Executive Summary of the study can be obtained at a price of $100.00 and $10.00, respectively, from the Purchasing Department, IFDC, P.O. Box 2040, Muscle Shoals, Alabama 35662, U.S.A.

(residual phosphorus and potassium in the soil) factors seem to have caused these slowdowns.

### *REGIONAL VARIATIONS*[2]

Not all regions experienced slowdown in fertilizer use growth during the 1980s. Asia and the U.S.S.R. experienced more than 5% annual growth in total fertilizer use. Latin America's and Africa's annual growth rates averaged 2.7% and 2.5%, respectively. Against this, total fertilizer use decreased in North America, Eastern Europe, and Oceania and increased marginally in Western Europe (Table 2).

Among different nutrients, all regions except North America experienced growth in nitrogen use, although at different rates. North America's small annual decrease is mostly due to low crop prices and acreage reduction programs.

Unlike nitrogen use, phosphate use decreased in several regions. Regions that experienced significant annual declines in $P_2O_5$ use are North America (−3.3%), Western Europe (−2.1%), Oceania (−2.9%), and Eastern Europe (−0.9%). Economic and policy changes as well as changes in cropping patterns have caused these decelerations in $P_2O_5$ use. The residual phosphorus in the soil also allowed the farmers in these regions to reduce or skip phosphate applications under the adverse economic circumstances of the 1980s.

Like phosphate use, potash use also decreased in many regions (North America, Western Europe, Eastern Europe, and Oceania) although the rate of annual decrease in potash use was lower than that in phosphate use in all these regions except North America.

The regional experience of the 1980s is in sharp contrast to that of the 1970s and 1960s. All regions experienced significant growth during the 1970s and the 1960s (Table 3).

### *REGIONAL SHARES*

Because of the varying growth rates experienced by different regions during the 1960-87 period, the shares of different regions in total and nutrientwise consumption have changed considerably. The striking changes are for North America and Western Europe as well as for Asia and the U.S.S.R. The shares of North America and Western Europe in global total fertilizer use decreased from 26% and 36% in 1960 to 15% and 16%, respectively, in 1987, whereas the shares of Asia and the U.S.S.R. increased sharply from 12% and 9% in 1960 to 31% and 19%, respectively, in 1987. Other regions experienced small changes in their shares (Figure 4).

## The Dynamics of Growth in Fertilizer Use

To understand the role of different factors in promoting or slowing growth in fertilizer use, the changes in fertilizer use during different 5-year periods are analyzed at the global and regional levels. Figure 5 indicates percentage changes during different 5-year periods in global fertilizer use, and Figures 6 and 7 indicate the similar changes at the regional level.

It is clear from Figure 5 that growth in fertilizer use accelerated during the 1975-80 period. This acceleration was caused by improved crop prices, rapid increase in global grain exports, and policy changes, especially in the developing countries.

Both nitrogen and phosphate use also experienced this acceleration during the 1975-80 period. However, potash use did not accelerate during the 1975-80 period. Agronomic and macroeconomic factors were responsible for this pattern in potash use.

Many regions, like North America, Western Europe, Oceania, and Asia, also experienced accelerated growth in fertilizer use during the 1975-80 period. Increased crop prices and the commodity boom of the late 1970s were responsible for this accelerated growth in fertilizer use in North America, Western Europe, and Oceania. The decreased crop prices and the mounting food surpluses reduced incentive to use fertilizers, and therefore, these regions experienced deceleration in fertilizer use growth in the 1980s.

Unlike North America and Western Europe, which experienced slowdown in growth, Asia continued to experience growth in fertilizer use because of policy stability and increased domestic production. Many Asian countries provided crop price support programs and fertilizer subsidies to promote growth in fertilizer use to achieve food security.

Eastern Europe's growth in fertilizer use accelerated in the 1965-70 period. After 1970, fertilizer use grew by decreasing percentages, and after 1980, it decreased. Unlike Western Europe, Eastern Europe's growth in fertilizer use was less sensitive to microeconomic changes of the late 1970s.

U.S.S.R.'s experience is quite opposite North America's or Western Europe's. Its growth in fertilizer use did not accelerate in the 1975-80 period. Rather, it accelerated in 1980-85 period because of emphasis on fertilizer use under its intensive technology programs to boost grain production.

Likewise, Latin America's experience is different from Asia's. Latin America experienced very little growth in the 1980-85 period, mostly because of microeconomic and macroeconomic policy changes. The removal of fertilizer subsidies in Venezuela and the subsidized credit programs in Brazil were some of the important microeconomic changes, and debt crises and foreign exchange shortages were important macroeconomic factors which affected growth in fertilizer

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[2] See Map 1 and Appendix A for the regional classification used in the study.

use in Latin America.

Africa's fertilizer use growth experience is a result of rapid growth in fertilizer use in North Africa and of decline in fertilizer use in South Africa. Also, foreign exchange shortages affected growth in fertilizer use in sub-Saharan Africa; most of the growth in fertilizer use in sub-Saharan Africa was achieved through aid-financed fertilizers.

## Trends in Fertilizer Production, 1960-87

### *GLOBAL TRENDS*

Total fertilizer production increased from 28.1 million tons in 1960 to 117.7 million tons in 1980 and 139.9 million tons in 1987. N, $P_2O_5$, and $K_2O$ production increased from 9.6, 9.8, and 8.7 million tons in 1960 to 59.6, 32.2, and 25.8 million tons in 1980 and 75.6, 35.6, and 28.8 million tons in 1987 (Table 4 and Figure 8).

Like the growth in fertilizer use, the growth in fertilizer production also slowed during the 1980s. Compared with 9.4% annual growth in the 1960s and 5.5% annual growth in the 1970s, total fertilizer production grew at 2.6% per annum during the 1980-87 period. All three nutrients experienced slowdown in production growth (Figure 9).

Although growth in global fertilizer production was slowed down in the 1980s, not all regions experienced the same degree of slowdown in their fertilizer production. In Asia, the U.S.S.R., Africa, and Latin America, fertilizer production grew at more than 6%, whereas in North America and Western Europe it decreased at about 1%/year. Oceania experienced the highest annual decline (5%/year) in its total fertilizer production, although it was mostly in $P_2O_5$ production (Table 5).

Most of the increase in total fertilizer production at the global level during the 1980s was contributed by increases in production in the U.S.S.R. and Asia where total fertilizer production increased by 12-13 million tons each. Increases in fertilizer production in these regions compensated for decreases of about 2-3 million tons in fertilizer production in North America and Western Europe. Africa, Latin America, and Eastern Europe contributed about 1-2 million tons each.

### *REGIONAL SHARES*

Because of the rapid growth experience by Asia and the U.S.S.R. during the 1970s and the 1980s, their shares in total world production increased sharply. In 1987, Asia accounted for 25% of total world production and the U.S.S.R. for about 24% (Figure 10). Thus, taken together these two regions accounted for nearly half of the world's total fertilizer production. This is in sharp contrast to their relatively small shares in 1960, when both of them taken together accounted for 14% of total production.

Compared with Asia and the U.S.S.R., North America and Western Europe experienced declines in their shares during the 1960-87 period. In 1960, these regions together accounted for 70% of the total production, but in 1987 their share was only 35%. Eastern Europe maintained its share at 10% during the 1960-87 period. Other regions experienced small changes.

## Fertilizer Demand Projections, 1987-95

### *GLOBAL DEMAND PROJECTIONS*

Global demand projections for N, $P_2O_5$, and $K_2O$ are presented in Table 6. The table also indicates annual growth rates for 1980-87 and 1987-95.

Total fertilizer use at the global level is projected to increase at 2.6% per annum during the 1987-95 period. Nitrogen use will increase at 2.8% per annum and $P_2O_5$ and $K_2O$ use at 2.7% and 2.1%, respectively. For $P_2O_5$ and $K_2O$, the projected growth rates are higher than those realized during the 1980-87 period because the projected improved micro- and macroeconomic prospects[3] during the forecast period will exert relatively more positive influence on their use than on nitrogen use. However, the projected growth rates for $P_2O_5$ and $K_2O$ are still lower than that for nitrogen, which itself is lower than what was realized during the 1980-87 period. A slightly lower growth rate for N during the 1987-95 period (compared with the 1980-87 period) is a result of its lower sensitivity to economic changes and the already high levels (both total and per hectare) and rapid growth achieved in many regions.

In absolute amounts, total fertilizer use is projected to increase from 132.3 million tons in 1987 to 163.5 million tons in 1995. Nitrogen use will increase from 72.4 million tons in 1987 to 90.5 million tons in 1995, while $P_2O_5$ and $K_2O$ use is expected to increase from 33.8 and 26.1 million tons in 1987 to 42.2 and 30.9 million tons, respectively, in 1995.

### *REGIONAL DEMAND PROJECTIONS*

The projected nutrientwise growth rates at the regional level are presented in Table 7, and the regional demand forecasts for N, $P_2O_5$, and $K_2O$ are presented in Tables 8, 9, and 10.

### *NITROGEN*

In Asia, nitrogen demand is projected to grow at 3.9% per annum from 28.4 million tons in 1987 to about 38.2 million tons in 1995. Asia will remain the leading region—in terms of both its contribution to

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[3] See World Bank *World Development Report*, 1988 (Washington, D.C.)

the growth in global N use and its own growth rate during the 1987-95 period.

All three subregions of Asia will experience more than 3% annual growth in nitrogen use. East Asia's N use will increase from 17.6 million tons in 1987 to 22.6 million tons in 1995, South Asia's from 8.6 million tons in 1987 to 12.4 million tons in 1995, and West Asia's from 2.1 million tons in 1987 to 3.3 million tons in 1995. Relatively lower annual growth in N use in East Asia is a result of its already high N use levels (both total and per hectare).

The U.S.S.R.'s nitrogen use is expected to increase at an annual rate of 2.8%-from 11.5 million tons in 1987 to 14.4 million tons in 1995. The slower growth in the U.S.S.R.'s N use during this period, compared with the 1980-87 period, is the result of earlier rapid growth in use and slowdown in capacity buildups. In contrast, North America's N use will grow at a faster rate during the forecast period compared with the 1980-87 period. This acceleration in N use in North America is a result of two factors. First, N use in North America is responsive to changes in crop prices, and crop prices are projected to remain remunerative during the forecast period. Second, the growing world demand for grain imports will also enhance fertilizer use in North America. Consequently, N use will increase from 10.5 million tons in 1987 to 12.8 million tons in 1995. In spite of this relatively higher growth, North America will add only a million tons in 1995 to its N use in 1985.

These regions, namely, Asia, the U.S.S.R., and North America, will account for a little less than three-fourths of global N use in 1995 (Figure 11).

Both Western Europe and Eastern Europe will experience modest increases in their N use levels; they will add less than a million tons each to their existing use levels. A drastic reduction in farm subsidies may slow down even this modest growth in Western Europe.

Latin America, Africa, and Oceania will experience 3% to 3.5% annual growth in their N use. Latin America's N use will increase from 3.8 million tons in 1987 to 5.0 million tons in 1995 and Africa's from 2.0 to 2.7 million tons. Sub-Saharan Africa's N use will increase from 0.65 million tons in 1987 to 0.95 million tons in 1995.

### *PHOSPHATE*

Asia will remain the leading region for growth in $P_2O_5$ demand also, in terms of both its contribution to global increase and its own growth rate.

North America, Western Europe, and Oceania are expected to see a reversal in their growth trends (from declining to increasing trends), whereas growth in Latin America's demand may accelerate a little. The growth rates in Asia and the U.S.S.R. will be lower during the forecast period, compared with the 1990s, because of their rapid growth during the 1980-87 period.

In Asia, $P_2O_5$ use will increase at 4.1% per annum—from 9.2 million tons in 1987 to 13.2 million tons in 1995. All three subregions will experience growth (Table 9).

The U.S.S.R. will add about 1.8 million tons to its 7.6 million tons $P_2O_5$ use in 1987.

In North America, $P_2O_5$ use is projected to grow at 2.2% per annum—from 4.3 million tons in 1987 to 5.1 million tons in 1995. This reversal in trend for North America is mostly due to an improved microeconomic situation projected at the global level. Western Europe and Eastern Europe will experience marginal increases in their $P_2O_2$ use.

Improved macroeconomic prospects for Latin America will help in increasing its $P_2O_5$ use at 2.9%. In absolute amount, Latin America's $P_2O_5$ use will increase from 2.8 million tons in 1987 to 3.5 million tons in 1995. More than 70% of the increase in $P_2O_5$ use will be contributed by South America.

Africa's $P_2O_5$ use will increase at 3.1% per annum; however, in absolute amount, it will be less than half a million tons—from 1.1 million tons in 1987 to 1.4 million tons in 1995. More than 65% of that increase will occur in North Africa. Sub-Saharan Africa's $P_2O_5$ use will increase by a small amount.

### *POTASH*

The U.S.S.R. will continue to dominate the global potash use. The U.S.S.R.'s potash consumption will increase by 1.4 million tons from 6.7 million tons in 1987 to 8.1 million tons in 1995. Although the U.S.S.R.'s growth rate will be lower during the 1987-95 period than in the 1980-87 period (2.4% versus 6.5%), the U.S.S.R. will still account for about a quarter of global potash use in 1995.

North America will add about 0.9 million tons to its 4.8 million tons $K_2O$ use in 1987. This reversal in growth trend in North America is caused by microeconomic changes mentioned earlier.

Although potash use is projected to grow slowly in Western Europe, it will remain the third largest region (after the U.S.S.R. and North America) in global potash consumption in 1995. In absolute amount, its potash consumption will increase by about half a million tons—from 5.2 million tons in 1987 to 5.7 million tons in 1995.

Asia's potash consumption will increase at 3.7% per annum from 3.4 million tons in 1987 to 4.6 million tons in 1995. About 63% of the increase will occur in East Asia, 34% in South Asia, and 3% in West Asia.

Latin America's potash consumption is projected to increase by a little less than half a million tons—from 2.0 million tons in 1987 to 2.4 million tons in 1995. About 70% of the projected increase will take place in South America.

In Oceania and Africa, $K_2O$ use is forecast to increase at about 4% per annum but from a small base; hence, it will have a minor impact on global potash use. In Eastern Europe also, potash use will increase by a small amount (Table 10).

## Fertilizer Supply Projections, 1987-95

The fertilizer supply projections are derived from fertilizer production projections by adjusting the latter for distribution losses. The fertilizer production projections are derived from the existing and the projected increases (expansions and new constructions) and decreases (closures) in nominal capacity of intermediate products and by making assumptions about phase-in factors, operating rates, conversion losses, and other sources of fertilizer nutrients.[4]

### Nitrogen

#### *PRODUCTION POTENTIAL*

The projected nitrogen production potential for the 1987-95 period is presented in Table 11. Although actual production data are available for 1987, we have calculated production potential for 1987 in order to identify the influence of depressed market conditions on actual production. A comparison of actual production with estimated production potential for 1987 indicates that actual global N production was 6.0% below the technically possible maximum production because about 2 million tons capacity was lying idle and many plants operated much below the normal operating rates due to low and unremunerative prices.

Global N production potential will increase from 80.3 million tons in 1986/87 to 91.3 million tons in 1994/95.

Asia and the U.S.S.R. will contribute nearly 77% of the increase in N production and Latin America and Africa another 21%, leaving only 2% for North America, Western Europe, and Eastern Europe—all the traditionally dominant producers and propellers of N production growth.

Asia will increase its production potential by about 6 million tons during the forecast period, and in Asia, South Asia will contribute nearly half of that increase and East Asia a little less than two-fifths.

North America's production potential will remain unchanged, Western Europe's will decrease, and Eastern Europe's will increase marginally.

The U.S.S.R.'s production potential will increase by 2.2 million tons, Latin America's by 1.7 million tons, and Africa's by 0.8 million tons. Sub-Saharan Africa will contribute more than 70% of the total increase in Africa's production potential.

By 1994/95, Asia's share in N production will be 37% and the U.S.S.R.'s 21%. Thus, more than half of the global N production will be produced in Asia and the U.S.S.R. North America's share will have decreased from 16% in 1987 to 13% in 1995; however, it will be the third largest region in N production (Figure 12).

#### *SUPPLY POTENTIAL*

Global nitrogen supply potential during the forecast period is indicated in the last row of Table 11; it is derived from global production potential after adjusting the latter for distribution losses or statistical discrepancy (4%).[5]

Global nitrogen supply potential will increase from 77.1 million tons in 1986/87 to 87.7 million tons in 1994/95—an annual growth of 1.6%. Compared with 2.8% projected annual growth in nitrogen demand, a 1.6% annual growth in supply potential indicates that during the 1990s, nitrogen supply will fall short of demand. The supply-demand balances described below indicate that the shortages will accentuate by the mid-1990s. Because the construction of fertilizer plants is a time-consuming process, investment in new capacity should be initiated now to avoid shortages in the mid-1990s.

### Phosphate

#### *PRODUCTION POTENTIAL*

$P_2O_5$ production potential is derived from both phosphoric acid capacity and non-phosphoric acid sources like SSP, nitrophosphate, and the phosphate rock content of TSP and other products.

Projected $P_2O_5$ production potential at the global and regional levels is indicated in Table 12. At the global level, production potential is projected to increase from 39.0 million tons in 1987 to 43.5 million tons in 1995.

Asia and Africa will contribute nearly two-thirds of the projected increase in global phosphate production potential. In Africa, North Africa will contribute most of the projected increase in production, while in Asia, East Asia will provide the lion's share. In addition to Asia and Africa, the U.S.S.R. will also contribute about one-fifth of the projected increase in production potential. North America and Western Europe may experience declines in their production potential.

Although North America's production potential may decrease marginally, North America will still account for about one-fourth of total $P_2O_5$ production in 1995. Asia and the U.S.S.R. will account for about

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[4] The projections of production refer to technical maximum production obtainable from installed capacity. Hence these projections are not strictly comparable with actual production because actual production depends on both technical and market conditions.

[5] Because of the difficulties in estimating distribution losses at the regional level, supply potential of N, $P_2O_5$, and $K_2O$ is estimated only at the global level. See Chapter 5 of the main volume of the study for details.

18% each of global production. The shares of other regions will vary between 3% and 12% (Figure 12).

### *SUPPLY POTENTIAL*

Global phosphate supply potential (indicated in the last row of Table 12) is projected to increase from 37.1 million tons in 1986/87 to 41.3 million tons in 1994/95. Because of the excess capacity in place and slower growth in phosphate use, the supply potential will exceed the projected demand until 1994. In 1995, however, a deficit of about 1 million tons may emerge.

## Potash

### *PRODUCTION POTENTIAL*

Global potash production potential is projected to increase by 1.7 million tons $K_2O$—from 31.2 million tons in 1987 to 32.9 million tons $K_2O$ in 1995 (Table 13). This modest increase in production potential is a consequence of existing excess capacity and stocks.

Most of the increase in global potash production potential will be contributed by increases in production potential in Asia and the U.S.S.R. The U.S.S.R.'s production potential is expected to increase from 10.2 million tons $K_2O$ in 1987 to 11.3 million tons in 1995 and Asia's production potential from 1.8 million tons in 1987 to 2.4 million tons in 1995. The production potential of North America and Western Europe is expected to remain unchanged, whereas that of Western Europe may decrease during the forecast period.

Although Asia will contribute about 35% of the projected increase in production potential, its share in global potash production will still remain small (7.5%) in 1995. North America (33%) and the U.S.S.R. (34%) will remain dominant producers and suppliers of potash fertilizers.

### *SUPPLY POTENTIAL*

Global potash supply potential (indicated in the last row of Table 13) is projected to increase from 29.7 million tons in 1987 to 31.2 million tons in 1995. In spite of this modest increase in production potential, no shortages of potash fertilizers are expected by the mid-1990s because of excess capacity currently in place.

## Fertilizer Supply-Demand Balances, 1987-95

Global and regional supply-demand balances for nitrogen, phosphate, and potash are discussed below. The supply-demand balance for each nutrient is defined as the difference between supply (global) or production (regional) potential and demand.

Sensitivity analysis of the projected supply-demand balances indicates that the nitrogen situation will be in *fragile* balance, the phosphate situation in *stable* balance, and the potash situation one of *surplus* in the mid-1990s.

## Nitrogen Supply-Demand Balances

### *GLOBAL BALANCES*

The global supply-demand balances are presented in Figure 13.

Three different scenarios are developed for estimating the supply potential. The base case scenario uses the assumed capacity utilization rates, or operating rates.[6]

In the High CU scenario, the capacity utilization rates are *increased* by one percentage point, and in the Low CU scenario, the capacity utilization rates are *decreased* by one percentage point in all regions.

Under the base case scenario, the supply potential exceeds the projected demand until 1990 and falls short of demand thereafter. Although the projected demand exceeds the supply potential by 1.3 million tons (shortage situation) in 1991, the deficit narrows to 0.2 million tons in 1992 and then gradually increases to 2.8 million tons in 1995 (Figure 13). The significantly higher deficits in 1991 are a result of rapidly growing demand and very little increase in capacity. In 1992, when many new plants are commissioned, and the growth in demand slows down (compared with 1991), the gap between demand and supply narrows. After 1992, as demand continues to grow without matching increases in capacity, the gap widens.

In the High CU scenario, the shortages of the 1991-94 period change into surpluses (except in 1991 when a deficit of 0.3 million tons still remains), and the deficits of 1995 are reduced from 2.8 million tons to 1.8 million tons. In the Low CU scenario, marginal shortages develop even in 1990 and accentuate thereafter. By 1995 the shortages increase to 3.8 million tons—1 million tons higher than the shortage of the base case scenario and 2 million tons higher than that of the High CU scenario.

This sensitivity analysis of changes in operating rates and their impact on supply-demand balances suggests that, although investment in capacity is required in the long run, the short-run shortages can be mitigated by improving capacity utilization or by improving what economists call the "ex-efficiency," that is, improving plant management by better planning, coordination, and waste reductions in the use of raw materials, machine time, labor services, and other operations.

### *REGIONAL BALANCES*

The supply-demand balances at the regional levels are presented in Table 14. By the absolute size of their surpluses or shortages, two regions stand out dis-

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[6] In all tables and graphs, a *positive* balance indicates surplus or excess of supply/production potential over demand, and a *negative* (indicated by a *minus* [ − ] sign) balance indicates *shortage* (deficit), or supply/production potential less than demand.

tinctly—the U.S.S.R. and Asia. During the forecast period, the U.S.S.R.'s surpluses will be more than 5 million tons in each year (except 1995), whereas Asia's deficits will gradually increase from 1.8 million tons in 1987 to 5.3 million tons in 1995.[7] It is rather interesting that although Asia will contribute more than 55% toward increase in global production during the 1987-95 period, this region will not be able to become self-sufficient in nitrogen production even by the end of this century. Consequently, Asia will continue to depend on nitrogen imports, and because of the size of its imports, it will play a dominant role in setting world prices.

In Asia, both East Asia and South Asia will remain deficit regions, and their deficits will increase from 0.6-1.8 million tons in 1987 to 2.5-3.0 million tons in 1995. Against this, West Asia will continue to experience annual surpluses of 0.4-0.9 million tons during the 1987-95 period.

North America and Western Europe will experience shortages of varying magnitudes during the 1990s. However, if crop price support programs are changed and farm subsidies are drastically reduced, these regions may not experience as much shortage as is predicted here because demand will be reduced.

Unlike Western Europe, Eastern Europe will have surpluses of the order of 2-3 million tons each during the 1987-95 period. Eastern Europe's surpluses are more a result of excess capacity already in existence and slow growth in demand.

Latin America and Africa will also have nitrogen surpluses although their surpluses will be of smaller magnitude. Latin America's surpluses will be concentrated in Central America and Africa's in North Africa.

## Phosphate Supply-Demand Balances

*GLOBAL BALANCES*

Figure 14 indicates phosophate supply-demand balances at the global level.

Under all scenarios, supply potential will exceed the projected demand through 1993. In 1994, under the Low CU scenario, supply will fall short of demand by about 0.43 million tons. However, the projected demand will exceed the supply potential under all three scenarios in 1995. The deficits or shortages will vary between 0.53 million tons (High CU scenario) and 1.19 million tons (Low CU scenario). Under the base case scenario, the shortages will amount to about 0.86 million tons. Thus, compared with the nitrogen situation, the phosphate situation will be more stable.

Under the base case scenario, the surpluses will gradually decrease from 3.73 million tons in 1988 to about 0.56 million tons in 1993 (Figure 14).

*REGIONAL BALANCES*

Regional phosphate supply-demand balances are presented in Table 15. The regions that stand out distinctly for their surpluses and deficits are North America and Africa (North Africa) for surpluses and Asia, Latin America, and the U.S.S.R. for shortages. Compared with these regions, Western Europe's shortages and Eastern Europe's surpluses are marginal.

During the 1987-95 period, North America's sur pluses will exceed 5 million tons per annum. In anticipation of the rising prices of the late 1970s and the early 1980s, investments in capacity expanded rapidly. However, as the demand decreased significantly during the 1980s, North America was left with excess capacity. Hence, in spite of little increase in capacity planned during the forecast period, North America will continue to have surpluses and therefore will continue to export phosphate products.

Africa's surpluses mostly originate in North Africa. Morocco and Tunisia are important producers and exporters of processed phosphates. North Africa will continue to maintain a dominant position in the world phosphate industry during the forecast period. Sub-Saharan Africa is a deficit region and will continue to depend on imports in the future.

Asia's deficits will continue to grow during the forecast period. In absolute amounts, these deficits will increase from 2.8 million tons in 1987 to 5.3 million tons in 1995. Like nitrogen deficits, Asia's phosphate deficits are also concentrated in East and South Asia. West Asia will have marginal deficits only in 1995.

Like Asia, Latin America will also continue to have deficits in its phosphate fertilizer supplies and therefore will continue to depend on imports. However, Latin America's deficits will originate in South America because Central America will remain self-sufficient in $P_2O_5$ production.

The U.S.S.R. is the third region whose phosphate deficits will increase—from 0.6 million tons in 1987 to 1.6 million tons in 1995 (Table 15). The U.S.S.R.'s phosphate deficits are in sharp contrast to its nitrogen and potash surpluses. Because of its surpluses in the other two nutrients, the U.S.S.R. was less constrained in importing its $P_2O_5$ requirements during the 1980s. North America and the U.S.S.R. exchange phosphoric acid and ammonia through mutual trade arrangements.

## Potash Supply-Demand Balances

*GLOBAL BALANCES*

Global potash supply-demand balances are presented in Figure 15. Because the supply potential will continue to exceed the projected demand during the forecast period, no sensitivity analysis is done; only the base case results are presented and analyzed.

Unlike the fragile nitrogen and the stable phos-

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[7] Regional N, $P_2O_5$, and $K_2O$ supply demand balances for different years during the 1987-95 period are analyzed in Chapter 6 of the main volume of the study.

phate situations, the potash situation will be one of surplus. During the forecast period, supply potential will continue to exceed the projected demand. Even in 1995, the supply potential will exceed the projected demand by 370,000 tons of $K_2O$. During the 1988-93 period, potash surpluses will range between 2.7 and 1.2 million tons of $K_2O$. On the basis of existing capacity and plans, potash shortages are likely to develop only after the mid-1990s.

## *REGIONAL BALANCES*

Potash resources are concentrated mostly in North America, the U.S.S.R., and West Asia; thus, many regions are currently deficit and will remain so during the forecast period. Table 16 indicates regional potash supply-demand balances.

North America and the U.S.S.R. are the only two regions that will have substantial potash surpluses during the forecast period. Their surpluses will vary between 3 and 6 million tons. All other regions will experience potash shortages and will be import-dependent. Asia's shortages will increase from 1.6 million tons in 1987 to 2.1 million tons in 1995. In Asia, both East and South Asia will have to depend on potash imports, whereas West Asia will have about 1.7-2.2 million tons of annual potash surplus for exports.

What is strikingly different about the potash situation is that, although most of the production is concentrated in only two regions (North America and the U.S.S.R.), these two regions have created so much excess capacity during the 1980s that their excess capacity will be more than sufficient to meet the growing demand in all regions during the 1990-95 period. This implies that earlier capacity expansions took place under highly optimistic expectations for growth in demand.

**TABLE 1**
**GLOBAL FERTILIZER CONSUMPTION, 1960-87**

| Year | N | $P_2O_5$ | $K_2O$ | Total |
|---|---|---|---|---|
| | | (million tons) | | |
| 1960 | 9.54 | 9.76 | 8.13 | 27.44 |
| 1965 | 16.38 | 14.01 | 10.93 | 41.33 |
| 1970 | 28.17 | 18.80 | 15.14 | 62.11 |
| 1975 | 38.50 | 22.86 | 19.50 | 80.86 |
| 1980 | 57.19 | 29.89 | 24.00 | 111.08 |
| 1985 | 70.51 | 33.01 | 25.90 | 129.43 |
| 1986 | 69.97 | 32.38 | 25.58 | 127.93 |
| 1987 | 72.37 | 33.84 | 26.09 | 132.31 |

Source: FAO *Fertilizer Yearbook* (various issues) and *Computer Data Tape.*

**TABLE 2**
**REGIONAL NITROGEN, PHOSPHATE, POTASH, AND TOTAL NPK CONSUMPTION: ANNUAL GROWTH RATES, 1980-87**

| Region | Nitrogen | Phosphate | Potash | Total |
|---|---|---|---|---|
| | | (%) | | |
| North America | −0.6 | −3.3 | −2.9 | −1.8 |
| Western Europe | 1.7 | −2.1 | −0.1 | 0.3 |
| Eastern Europe | 0.4 | −0.9 | −0.3 | −0.2 |
| U.S.S.R. | 6.1 | 6.8 | 6.5 | 6.4 |
| Oceania | 6.2 | −2.9 | −0.1 | −0.7 |
| Africa | 2.9 | 1.8 | 2.8 | 2.5 |
| North Africa | 4.4 | 5.0 | 6.4 | 4.8 |
| Sub-Saharan Africa | 5.4 | 6.9 | 3.7 | 5.5 |
| South Africa | −3.5 | −4.9 | −1.3 | −3.8 |
| Latin America | 4.5 | 1.0 | 2.1 | 2.7 |
| Central America | 4.8 | 4.6 | 3.3 | 4.5 |
| South America | 4.2 | 0.2 | 1.8 | 1.9 |
| Asia | 5.6 | 6.4 | 4.5 | 5.7 |
| East Asia | 4.0 | 4.5 | 3.1 | 4.0 |
| South Asia | 8.9 | 11.1 | 7.1 | 9.3 |
| West Asia | 8.0 | 5.5 | 11.9 | 7.1 |
| World | 3.5 | 1.9 | 1.5 | 2.6 |

Source: Derived from FAO data using log-linear regressions.

**TABLE 3**
**REGIONAL GROWTH IN FERTILIZER (TOTAL NUTRIENT) USE: ANNUAL GROWTH RATES, 1960-87**

| | 1960-70 | 1970-80 | 1980-87 |
|---|---|---|---|
| | | (%) | |
| North America | 8.4 | 4.0 | −1.8 |
| Western Europe | 4.8 | 2.1 | 0.3 |
| Eastern Europe | 11.0 | 4.4 | −0.2 |
| U.S.S.R. | 14.7 | 7.9 | 6.4 |
| Oceania | 6.9 | 0.6 | −0.7 |
| Africa | 9.4 | 6.2 | 2.5 |
| Latin America | 11.9 | 9.8 | 2.7 |
| Asia | 12.1 | 9.6 | 5.7 |
| World | 8.9 | 5.6 | 2.6 |

Source: Derived from FAO data.

**TABLE 4**
**GLOBAL FERTILIZER PRODUCTION, 1960-87**

| Year | N | $P_2O_5$ | $K_2O$ | Total |
|---|---|---|---|---|
| | | (million tons) | | |
| 1960 | 9.64 | 9.77 | 8.71 | 28.12 |
| 1965 | 17.66 | 14.60 | 12.19 | 44.45 |
| 1970 | 30.22 | 19.45 | 16.66 | 66.33 |
| 1975 | 42.46 | 25.84 | 23.40 | 91.70 |
| 1980 | 59.62 | 32.22 | 25.84 | 117.69 |
| 1985 | 74.52 | 35.62 | 28.66 | 138.80 |
| 1987 | 75.56 | 35.55 | 28.79 | 139.91 |

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

## TABLE 5
## REGIONAL NITROGEN, PHOSPHATE, POTASH, AND TOTAL NPK PRODUCTION: ANNUAL GROWTH RATES, 1980-87

| Region | Nitrogen | Phosphate | Potash | Total |
|---|---|---|---|---|
| | (%) | | | |
| North America | −0.7 | −1.0 | −1.7 | −1.1 |
| Western Europe | −0.3 | −3.5 | −1.4 | −1.3 |
| Eastern Europe | 2.2 | 0.0 | 0.3 | 1.2 |
| U.S.S.R. | 7.0 | 5.8 | 5.8 | 6.3 |
| Oceania | 4.2 | −6.8 | — | −5.0 |
| Africa | 10.0 | 6.6 | — | 8.3 |
| North Africa | 18.5 | 11.5 | — | 14.7 |
| Sub-Saharan Africa | −0.3 | −0.3 | — | −0.2 |
| South Africa | −0.8 | −2.3 | — | −1.3 |
| Latin America | 10.0 | 2.3 | — | 6.5 |
| Central America | 9.9 | 3.0 | — | 8.1 |
| South America | 10.0 | 2.2 | — | 5.2 |
| Asia | 5.7 | 5.8 | 13.3 | 6.0 |
| East Asia | 3.5 | 2.2 | 5.6 | 3.2 |
| South Asia | 12.5 | 10.7 | — | 12.4 |
| West Asia | 6.8 | 15.0 | 13.4 | 10.4 |
| World | 3.6 | 1.5 | 1.6 | 2.6 |

Source: Derived from FAO data using log-linear regressions. FAO (1988).

## TABLE 6
## GLOBAL DEMAND PROJECTIONS, 1990 AND 1995

| | | | | Annual Growth Rates | |
|---|---|---|---|---|---|
| Nutrient | Actual 1987 | 1990 | 1995 | 1980-87 | 1987-95 |
| | (million tons) | | | (%) | |
| N | 72.37 | 80.34 | 90.51 | 3.5 | 2.8 |
| $P_2O_5$ | 33.84 | 37.66 | 42.16 | 1.9 | 2.7 |
| $K_2O$ | 26.09 | 28.41 | 30.87 | 1.5 | 2.1 |
| Total | 132.30 | 146.41 | 163.54 | 2.6 | 2.6 |

Source: FAO *Fertilizer Yearbook,* 1987 for actual, and IFDC Publication T-34 for projections.

## TABLE 7
## PROJECTED NITROGEN, PHOSPHATE, POTASH, AND TOTAL NPK DEMANDS IN DIFFERENT REGIONS: ANNUAL GROWTH RATES, 1987-95

| Region | Nitrogen | Phosphate | Potash | Total NPK |
|---|---|---|---|---|
| | (%) | | | |
| North America | 2.3 | 2.2 | 2.1 | 2.2 |
| Western Europe | 0.3 | 1.0 | 1.0 | 0.6 |
| Eastern Europe | 1.2 | 1.0 | 0.7 | 1.0 |
| U.S.S.R. | 2.8 | 2.8 | 2.4 | 2.7 |
| Oceania | 3.0 | 2.1 | 4.2 | 2.7 |
| Africa | 3.4 | 3.1 | 3.7 | 3.4 |
| North Africa | 3.4 | 4.0 | 4.5 | 3.7 |
| Sub-Saharan Africa | 4.6 | 3.7 | 4.0 | 4.2 |
| South Africa | 1.2 | 1.3 | 2.2 | 1.4 |
| Latin America | 3.5 | 2.9 | 2.5 | 3.1 |
| Central America | 3.1 | 3.2 | 3.4 | 3.2 |
| South America | 4.0 | 2.9 | 2.2 | 3.0 |
| Asia | 3.9 | 4.1 | 3.7 | 3.9 |
| East Asia | 3.3 | 3.3 | 3.4 | 3.3 |
| South Asia | 4.9 | 5.2 | 4.2 | 4.9 |
| West Asia | 5.5 | 4.5 | 3.4 | 5.0 |
| World | 2.8 | 2.7 | 2.1 | 2.6 |

Source: Derived from data in Tables 8, 9, and 10.

## TABLE 8
## PROJECTED NITROGEN DEMAND, 1990 AND 1995

| Region | 1987[a] | 1990 | 1995 |
|---|---|---|---|
| | ('000 tons) | | |
| North America | 10,539 | 12,069 | 12,753 |
| Western Europe | 10,656 | 11,514 | 11,479 |
| Eastern Europe | 5,055 | 5,215 | 5,545 |
| U.S.S.R. | 11,475 | 12,421 | 14,346 |
| Oceania | 406 | 439 | 514 |
| Africa | 2,010 | 2,251 | 2,656 |
| North Africa | 993 | 1,076 | 1,286 |
| Sub-Saharan Africa | 655 | 759 | 950 |
| South Africa | 362 | 415 | 420 |
| Latin America | 3,831 | 4,209 | 5,043 |
| Central America | 1,995 | 2,187 | 2,545 |
| South America | 1,836 | 2,022 | 2,498 |
| Asia | 28,398 | 32,221 | 38,174 |
| East Asia | 17,624 | 20,228 | 22,550 |
| South Asia | 8,630 | 9,354 | 12,358 |
| West Asia | 2,144 | 2,638 | 3,266 |
| World | 72,370 | 80,339 | 90,511 |

[a] Actual.
Note: Totals may not add due to rounding.
Source: FAO *Fertilizer Yearbook,* 1987 for actual and IFDC Publication T-34 for projections.

### TABLE 9
### PROJECTED PHOSPHATE DEMAND, 1990 AND 1995

| Region | 1987[a] | 1990 | 1995 |
|---|---|---|---|
| | | ('000 tons) | |
| North America | 4,283 | 4,850 | 5,118 |
| Western Europe | 4,798 | 4,848 | 5,088 |
| Eastern Europe | 3,110 | 3,307 | 3,402 |
| U.S.S.R. | 7,567 | 8,219 | 9,350 |
| Oceania | 981 | 1,036 | 1,129 |
| Africa | 1,112 | 1,256 | 1,442 |
| North Africa | 418 | 480 | 582 |
| Sub-Saharan Africa | 357 | 391 | 472 |
| South Africa | 337 | 385 | 388 |
| Latin America | 2,796 | 2,959 | 3,467 |
| Central America | 599 | 674 | 775 |
| South America | 2,197 | 2,285 | 2,692 |
| Asia | 9,198 | 11,189 | 13,164 |
| East Asia | 5,032 | 6,107 | 6,775 |
| South Asia | 2,866 | 3,507 | 4,443 |
| West Asia | 1,300 | 1,575 | 1,907 |
| World | 33,845 | 37,664 | 42,161 |

[a] Actual.

Note: Totals may not add due to rounding.

Source: FAO *Fertilizer Yearbook,* 1987 for actual and IFDC Publication T-34 for projections.

### TABLE 10
### PROJECTED POTASH DEMAND, 1990 AND 1995

| Region | 1987[a] | 1990 | 1995 |
|---|---|---|---|
| | | ('000 tons) | |
| North America | 4,792 | 5,363 | 5,651 |
| Western Europe | 5,213 | 5,669 | 5,708 |
| Eastern Europe | 3,345 | 3,316 | 3,491 |
| U.S.S.R. | 6,677 | 7,360 | 8,092 |
| Oceania | 221 | 270 | 310 |
| Africa | 445 | 503 | 594 |
| North Africa | 136 | 145 | 187 |
| Sub-Saharan Africa | 189 | 223 | 263 |
| South Africa | 119 | 135 | 144 |
| Latin America | 2,007 | 2,151 | 2,437 |
| Central America | 434 | 474 | 566 |
| South America | 1,572 | 1,677 | 1,871 |
| Asia | 3,396 | 3,777 | 4,589 |
| East Asia | 2,232 | 2,470 | 2,987 |
| South Asia | 1,019 | 1,163 | 1,425 |
| West Asia | 145 | 144 | 177 |
| World | 26,095 | 28,410 | 30,872 |

[a] Actual.

Note: Totals may not add due to rounding.

Source: FAO *Fertilizer Yearbook,* 1987 for actual and IFDC Publication T-34 for projections.

### TABLE 11
### PROJECTED NITROGEN FERTILIZER PRODUCTION POTENTIAL, 1990 AND 1995

| Region | 1987[a] | 1990 | 1995 |
|---|---|---|---|
| | | ('000 tons) | |
| North America | 11,767 | 11,850 | 11,715 |
| Western Europe | 9,843 | 9,411 | 9,280 |
| Eastern Europe | 7,796 | 8,182 | 8,237 |
| U.S.S.R. | 17,121 | 17,981 | 19,345 |
| Oceania | 406 | 410 | 651 |
| Africa | 2,164 | 2,459 | 3,046 |
| North Africa | 1,432 | 1,625 | 1,832 |
| Sub-Saharan Africa | 183 | 373 | 753 |
| South Africa | 549 | 460 | 460 |
| Latin America | 4,095 | 4,435 | 5,694 |
| Central America | 2,675 | 2,933 | 3,449 |
| South America | 1,419 | 1,501 | 2,245 |
| Asia | 26,584 | 29,283 | 32,869 |
| East Asia | 17,015 | 17,759 | 19,368 |
| South Asia | 6,836 | 7,985 | 9,814 |
| West Asia | 2,733 | 3,539 | 3,688 |
| World (A) | 80,277 | 84,511 | 91,337 |
| (B) | 77,066 | 81,131 | 87,683 |

[a] Estimated from existing capacity.

A = Production potential (totals may not add due to non-$NH_3$ production added to global production potential).

B = Supply potential (derived from production potential after adjusting it for distribution losses).

Source: IFDC Publication T-34.

### TABLE 12
### PROJECTED PHOSPHATE FERTILIZER PRODUCTION POTENTIAL, 1990 AND 1995

| Region | 1987[a] | 1990 | 1995 |
|---|---|---|---|
| | | ('000 tons $P_2O_5$) | |
| North America | 10,656 | 10,500 | 10,502 |
| Western Europe | 4,869 | 4,780 | 4,763 |
| Eastern Europe | 3,640 | 3,723 | 3,799 |
| U.S.S.R. | 6,937 | 7,413 | 7,730 |
| Oceania | 1,114 | 1,133 | 1,481 |
| Africa | 3,777 | 4,675 | 5,236 |
| North Africa | 2,737 | 3,605 | 4,167 |
| Sub-Saharan Africa | 281 | 288 | 298 |
| South Africa | 759 | 781 | 791 |
| Latin America | 1,683 | 2,030 | 2,085 |
| Central America | 620 | 834 | 844 |
| South America | 1,063 | 1,196 | 1,241 |
| Asia | 6,347 | 7,294 | 7,860 |
| East Asia | 3,619 | 4,227 | 4,551 |
| South Asia | 1,169 | 1,447 | 1,538 |
| West Asia | 1,559 | 1,619 | 1,771 |
| World (A) | 39,024 | 41,747 | 43,476 |
| (B) | 37,073 | 39,660 | 41,302 |

[a] Estimated from existing capacity.

A = Production potential (totals may not add due to rounding).

B = Supply potential (derived from production potential after adjusting it for distribution losses).

Source: IFDC Publication T-34.

### TABLE 13
### PROJECTED POTASH FERTILIZER PRODUCTION POTENTIAL, 1990 AND 1995

| Region | 1987[a] | 1990 | 1995 |
|---|---|---|---|
| | ('000 tons $K_2O$) | | |
| North America | 10,526 | 10,835 | 10,658 |
| Western Europe | 5,483 | 5,155 | 5,155 |
| Eastern Europe | 3,160 | 3,160 | 3,160 |
| U.S.S.R. | 10,190 | 10,670 | 11,312 |
| Oceania | 0 | 0 | 0 |
| Africa | 0 | 0 | 0 |
| North Africa | 0 | 0 | 0 |
| Sub-Saharan Africa | 0 | 0 | 0 |
| South Africa | 0 | 0 | 0 |
| Latin America | 46 | 131 | 154 |
| Central America | 0 | 0 | 0 |
| South America | 46 | 131 | 154 |
| Asia | 1,844 | 2,044 | 2,448 |
| East Asia | 38 | 65 | 77 |
| South Asia | 0 | 0 | 0 |
| West Asia | 1,806 | 1,979 | 2,371 |
| World (A) | 31,249 | 31,995 | 32,887 |
| (B) | 29,687 | 30,395 | 31,242 |

[a]Estimated from existing capacity.
A = Production potential (totals may not add due to rounding).
B = Supply potential (derived from production potential after adjusting it for distribution losses).
Source: IFDC Publication T-34.

### TABLE 14
### NITROGEN: PROJECTED REGIONAL SUPPLY-DEMAND BALANCES, 1990 AND 1995[a]

| Region | 1987[b] | 1990 | 1995 |
|---|---|---|---|
| | ('000 tons $K_2O$) | | |
| North America | 1,229 | -219 | -1,038 |
| Western Europe | -812 | -2,103 | -2,199 |
| Eastern Europe | 2,741 | 2,967 | 2,692 |
| U.S.S.R. | 5,646 | 5,560 | 4,998 |
| Oceania | — | -28 | 137 |
| Africa | 154 | 208 | 390 |
| North Africa | 439 | 549 | 546 |
| Sub-Saharan Africa | -472 | -385 | -197 |
| South Africa | 187 | 45 | 40 |
| Latin America | 264 | 225 | 651 |
| Central America | 680 | 746 | 904 |
| South America | -416 | -521 | -253 |
| Asia | -1,814 | -2,938 | -5,305 |
| East Asia | -609 | -2,470 | -3,182 |
| South Asia | -1,794 | -1,368 | -2,544 |
| West Asia | 589 | 901 | 421 |

[a]Refers to base case.
[b]Based on actual consumption and estimated production potential.

### TABLE 15
### PHOSPHATE: PROJECTED REGIONAL SUPPLY-DEMAND BALANCES, 1987, 1990 AND 1995[a]

| Region | 1987[b] | 1990 | 1995 |
|---|---|---|---|
| | ('000 tons $K_2O$) | | |
| North America | 6,373 | 5,649 | 5,384 |
| Western Europe | 71 | -70 | -325 |
| Eastern Europe | 530 | 415 | 397 |
| U.S.S.R. | -630 | -805 | -1,620 |
| Oceania | 133 | 297 | 352 |
| Africa | 2,666 | 3,419 | 3,815 |
| North Africa | 2,319 | 3,125 | 3,585 |
| Sub-Saharan Africa | -76 | -103 | -174 |
| South Africa | 421 | 397 | 403 |
| Latin America | -1,114 | -929 | -1,382 |
| Central America | 21 | 160 | 69 |
| South America | -1,135 | -1,089 | -1,451 |
| Asia | -2,851 | -3,896 | -5,304 |
| East Asia | -1,412 | -1,820 | -2,224 |
| South Asia | -1,698 | -2,060 | -2,905 |
| West Asia | 259 | 44 | -136 |

[a]Refers to base case.
[b]Based on actual consumption and estimated production potential.

### TABLE 16
### POTASH: PROJECTED REGIONAL SUPPLY-DEMAND BALANCES, 1987, 1990 AND 1995

| Region | 1987[a] | 1990 | 1995 |
|---|---|---|---|
| | ('000 tons $K_2O$) | | |
| North America | 5,734 | 5,472 | 5,007 |
| Western Europe | 270 | -515 | -553 |
| Eastern Europe | -185 | -156 | -331 |
| U.S.S.R. | 3,512 | 3,310 | 3,220 |
| Oceania | -221 | -270 | -310 |
| Africa | -445 | -503 | -594 |
| North Africa | -136 | -145 | -187 |
| Sub-Saharan Africa | -189 | -221 | -263 |
| South Africa | -119 | -135 | -144 |
| Latin America | -1,961 | -2,021 | -2,283 |
| Central America | -434 | -474 | -566 |
| South America | -1,526 | -1,541 | -1,717 |
| Asia | -1,552 | -1,733 | -2,141 |
| East Asia | -2,193 | -2,405 | -2,910 |
| South Asia | -1,019 | -1,163 | -1,425 |
| West Asia | 1,660 | 1,835 | 2,194 |

[a]Based on actual consumption and estimated production potential.

**FIGURE 1**

WORLD: NITROGEN, PHOSPHATE, POTASH, AND TOTAL NPK CONSUMPTION, 1960-87

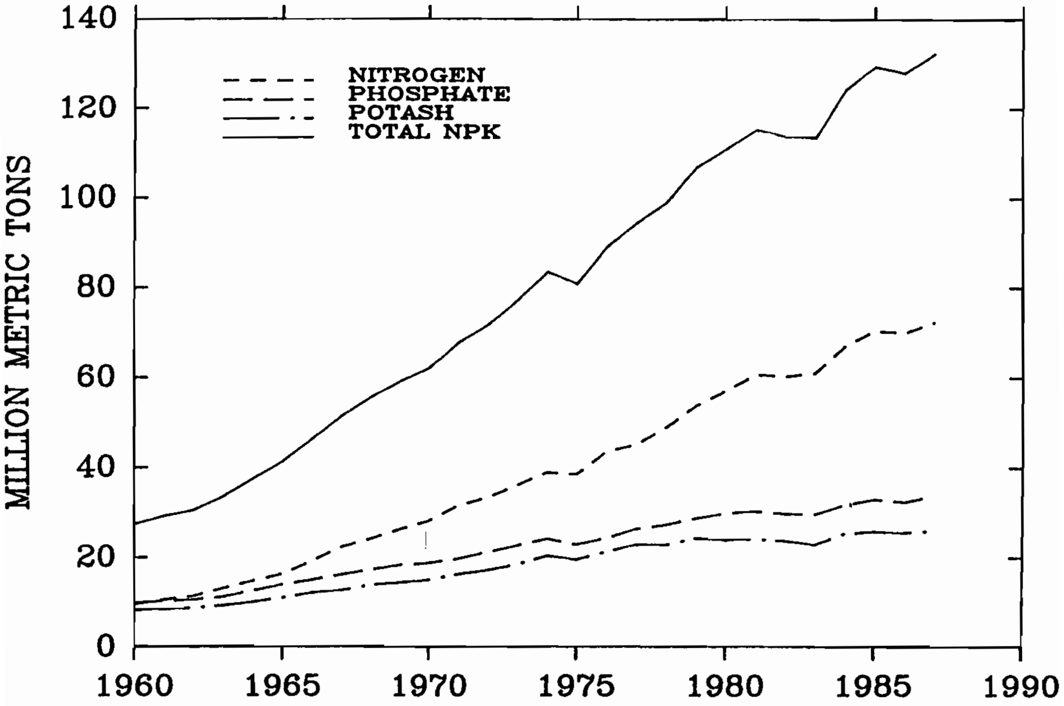
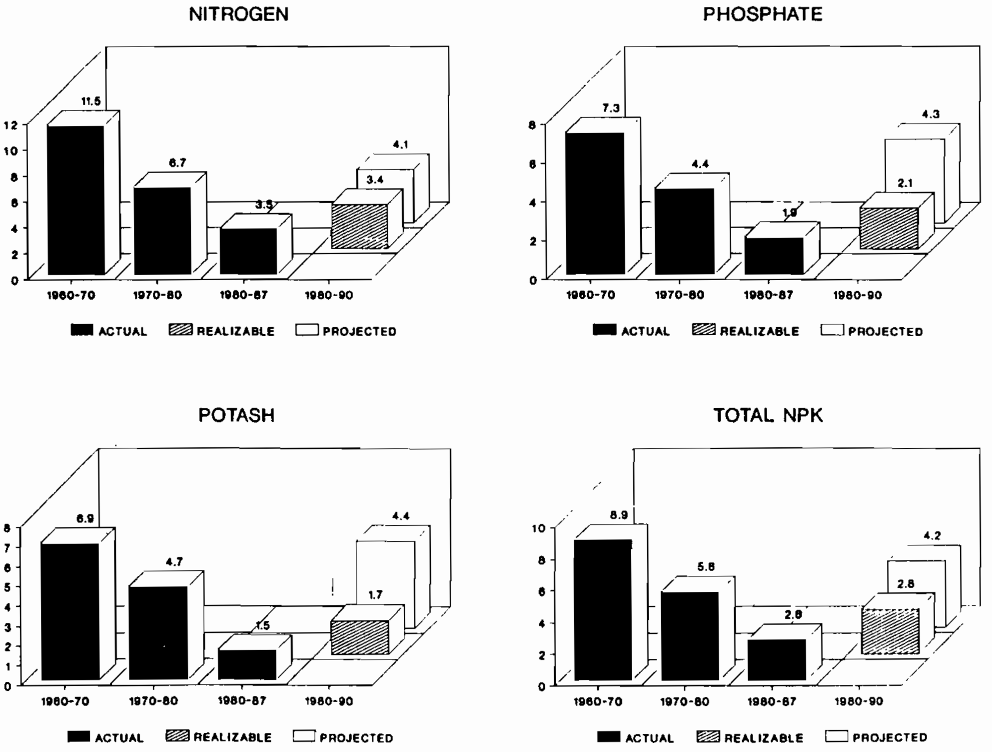


**FIGURE 2**

Global Fertilizer Use: Actual and Projected Annual Growth, 1960-90 (Percent)


NITROGEN

PHOSPHATE

POTASH

TOTAL NPK

FIGURE 3

## WORLD FERTILIZER USE: TOTAL & PER CAPITA
## 1950-88

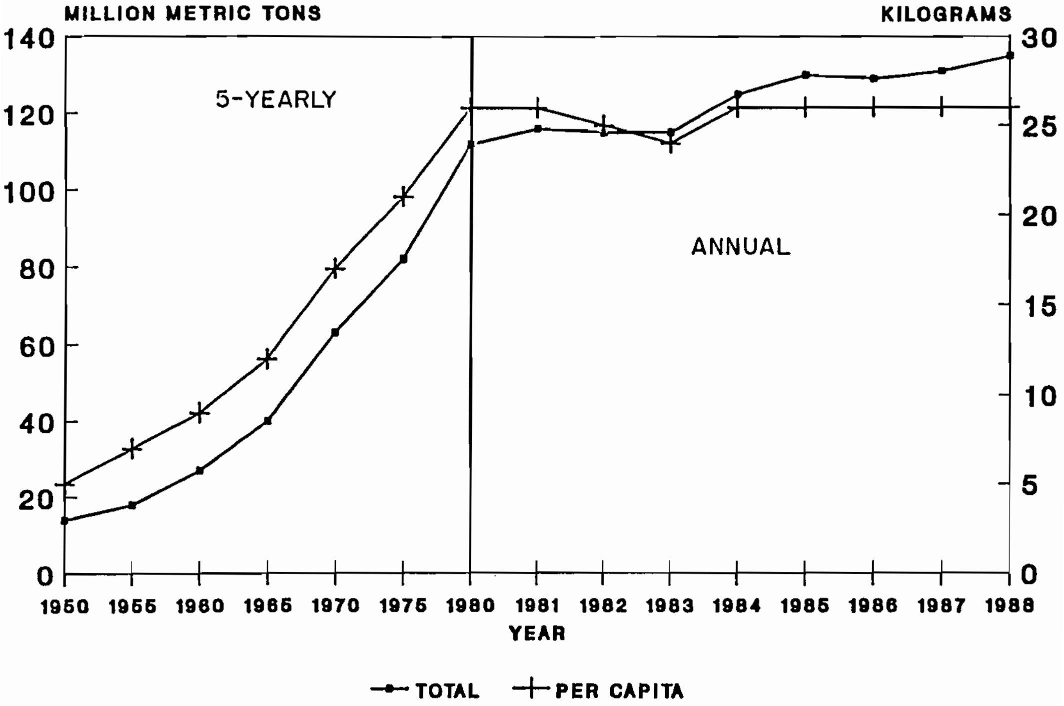
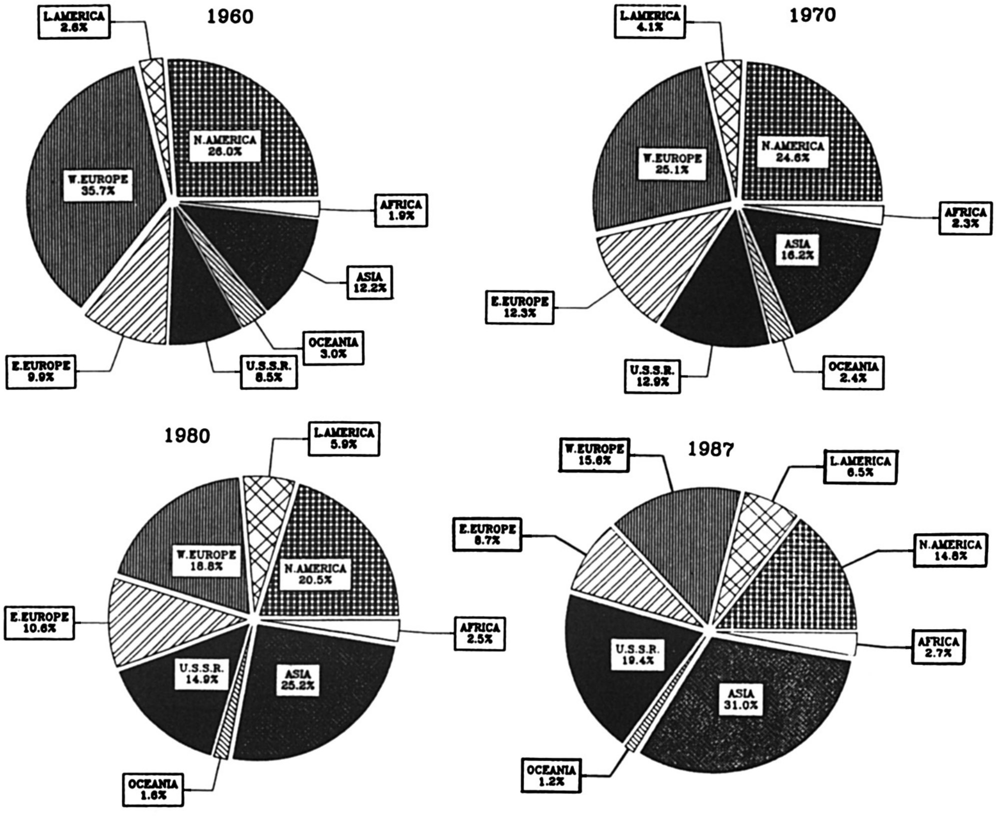


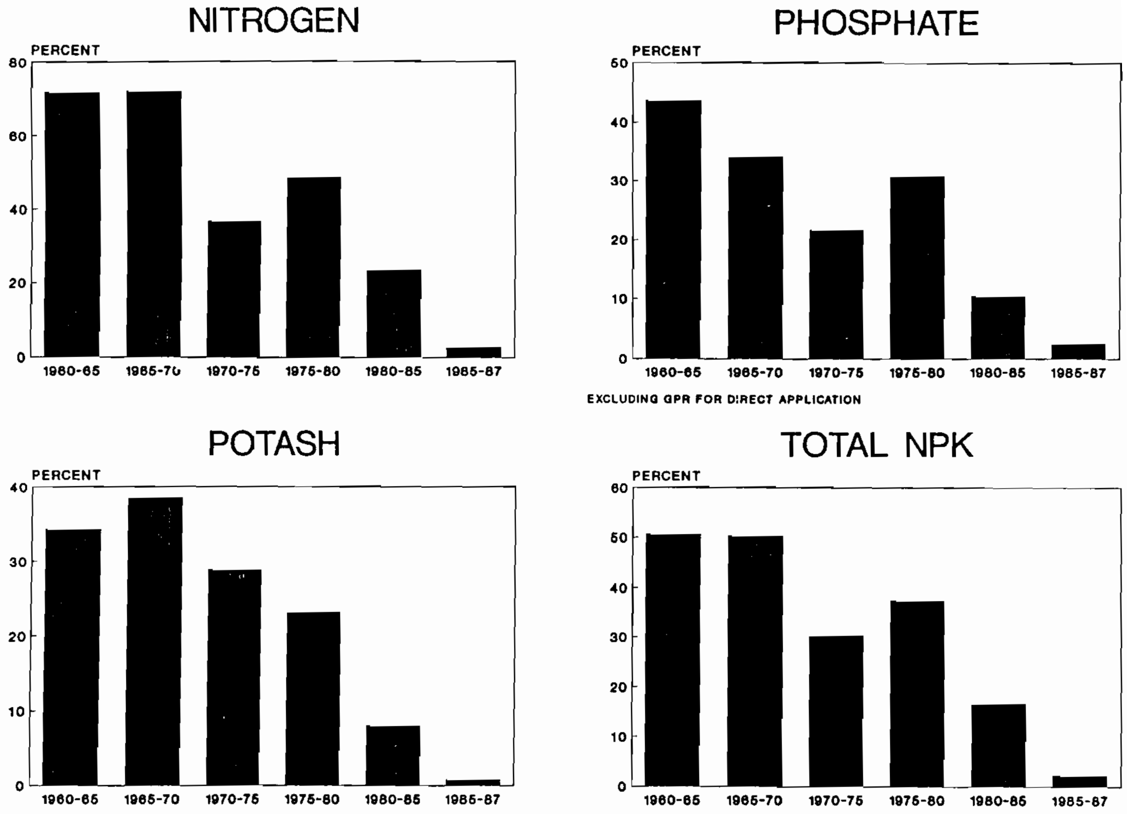
FIGURE 4

REGIONAL SHARES OF WORLD TOTAL NPK CONSUMPTION



## FIGURE 5

Percentage Changes in Global Fertilizer Use, 1960-87



EXCLUDING GPR FOR DIRECT APPLICATION

## FIGURE 6

Percentage Changes in Total NPK Consumption in North America, Europe, and the U.S.S.R., 1960-87

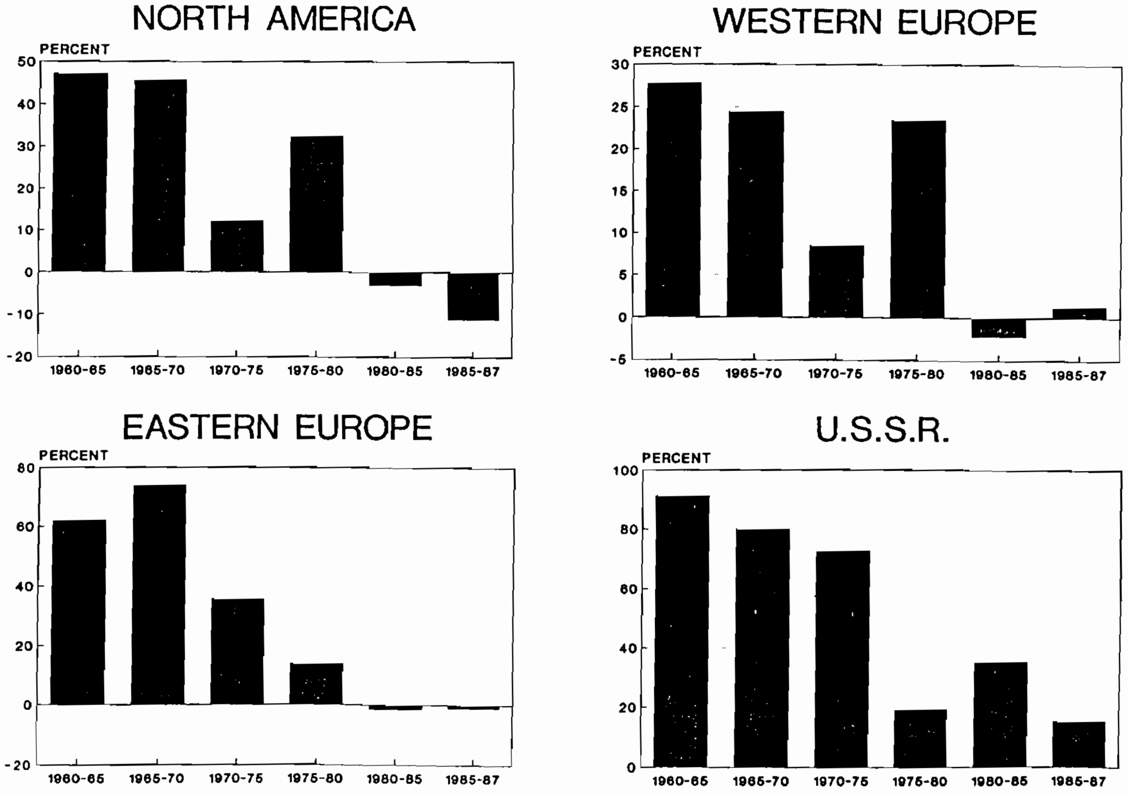


**FIGURE 7**

Percentage Changes in Total NPK Consumption in Africa, Asia, Latin America, and Oceania, 1960-87

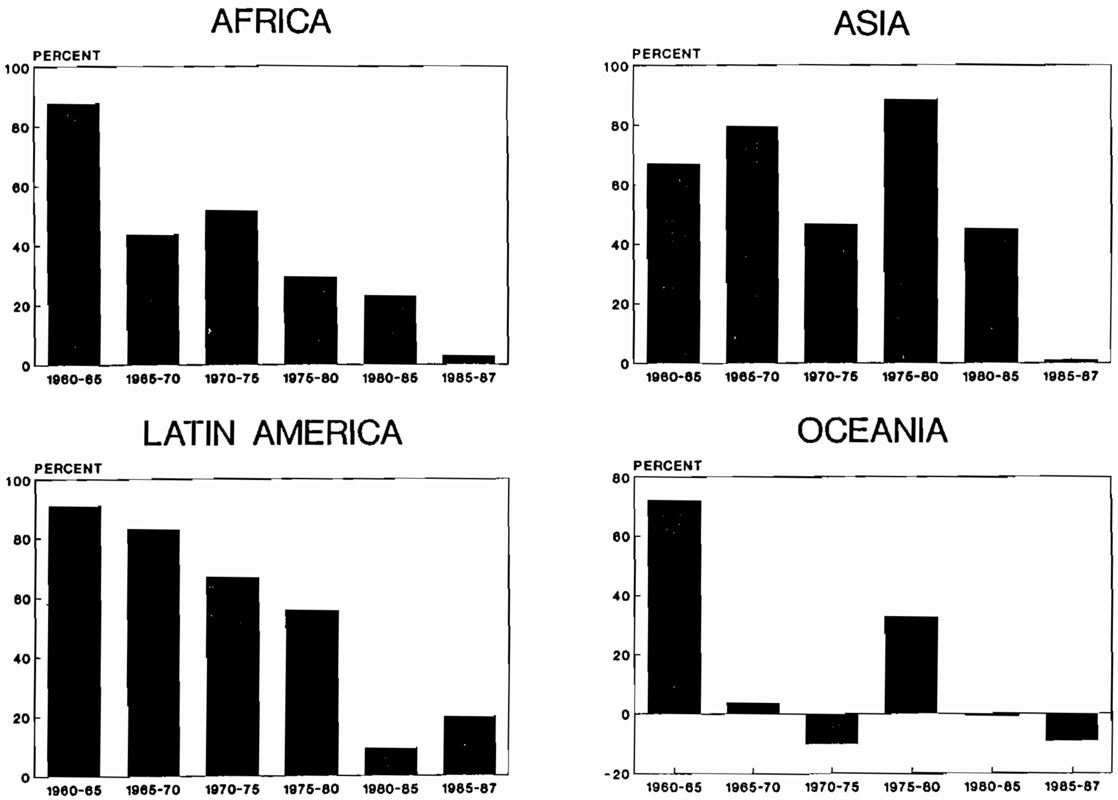
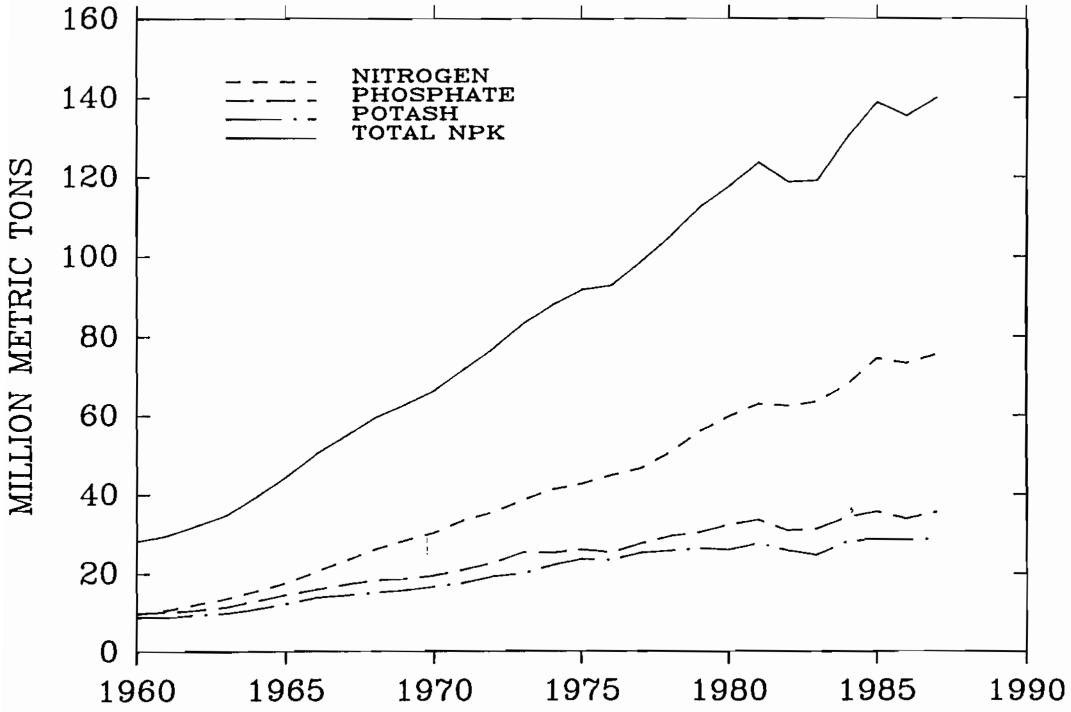


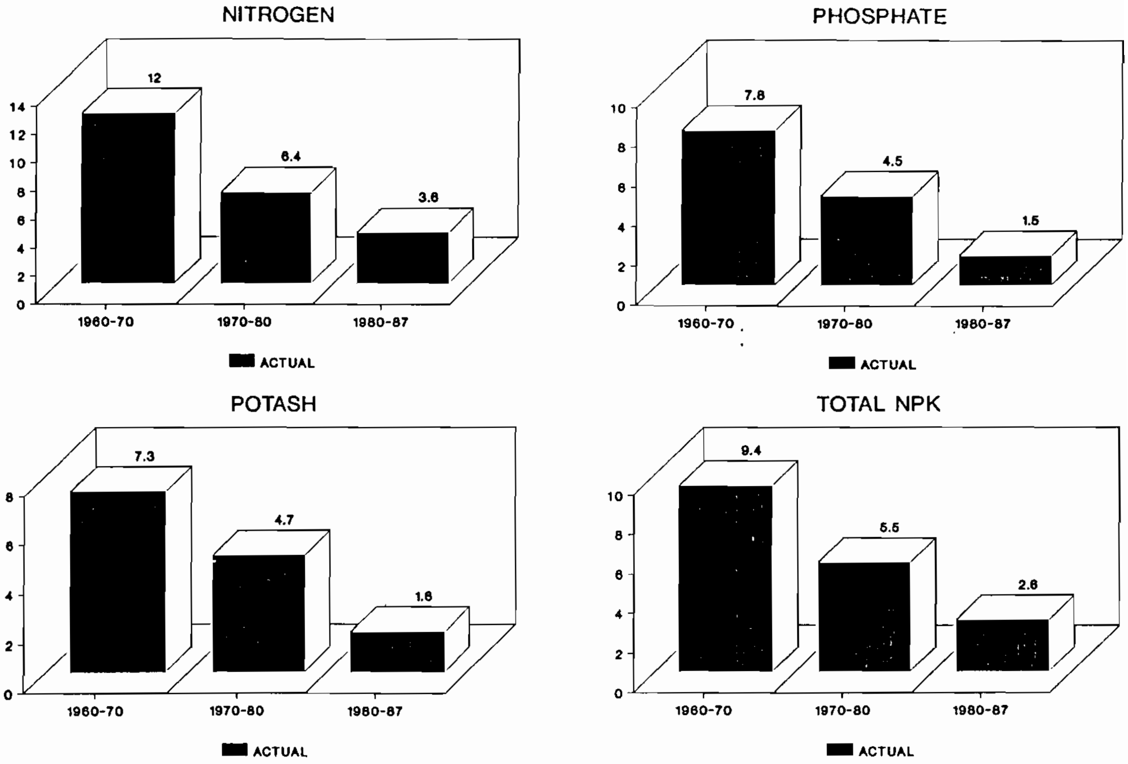
**FIGURE 8**

WORLD: NITROGEN, PHOSPHATE, POTASH, AND TOTAL NPK PRODUCTION, 1960–87



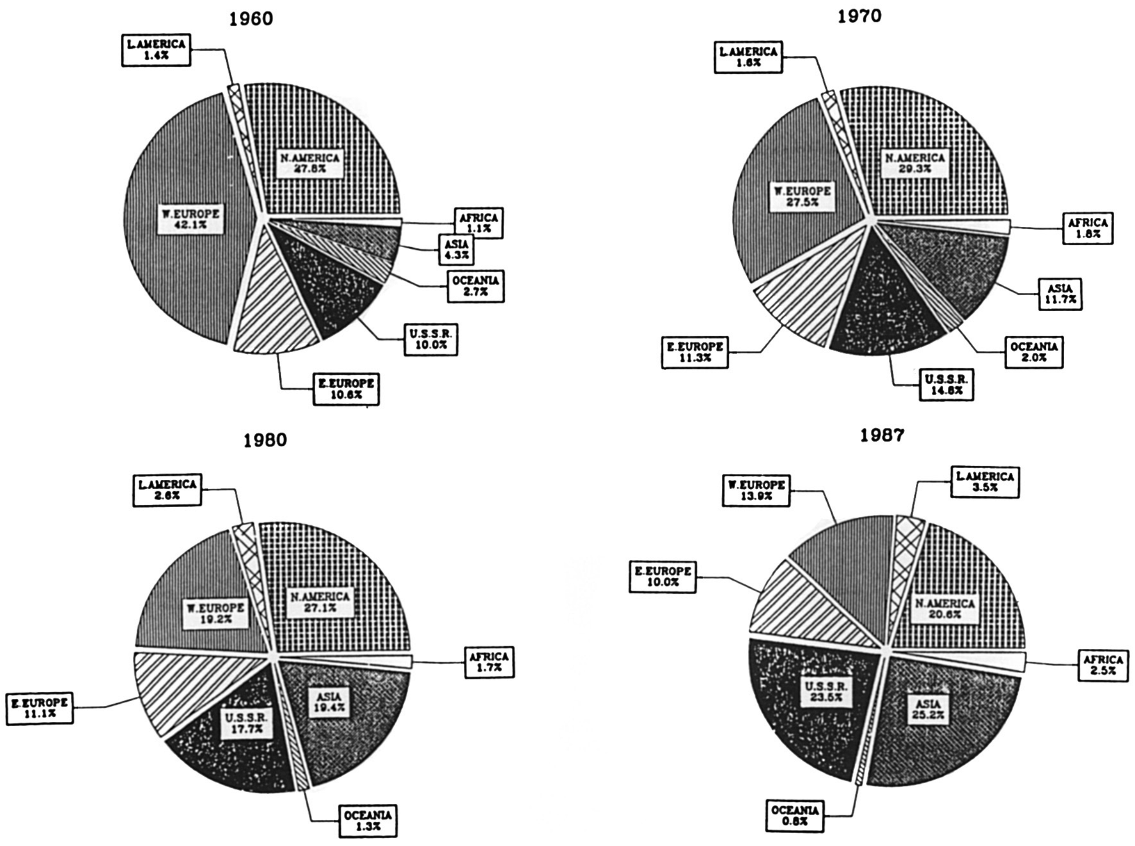
## FIGURE 9

Global Fertilizer Production, 1960-87: Annual Growth Rates (%)



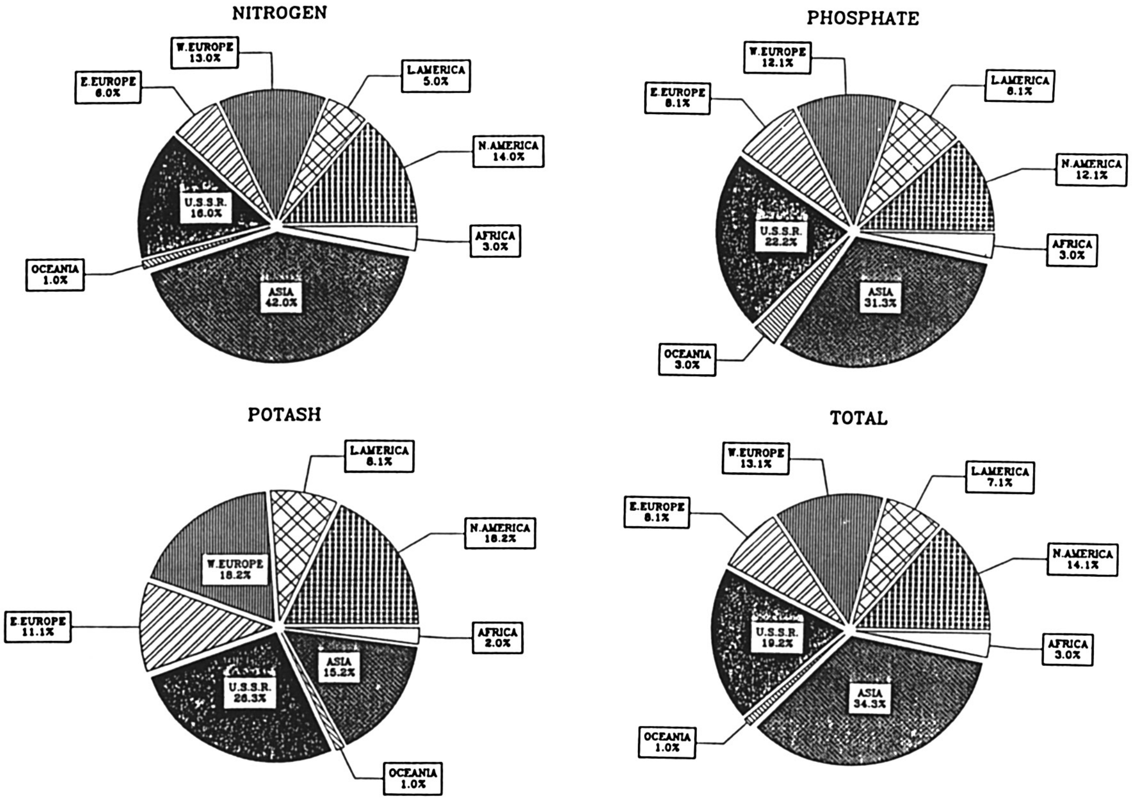
## FIGURE 10

REGIONAL SHARES OF WORLD TOTAL NPK PRODUCTION
1960–87



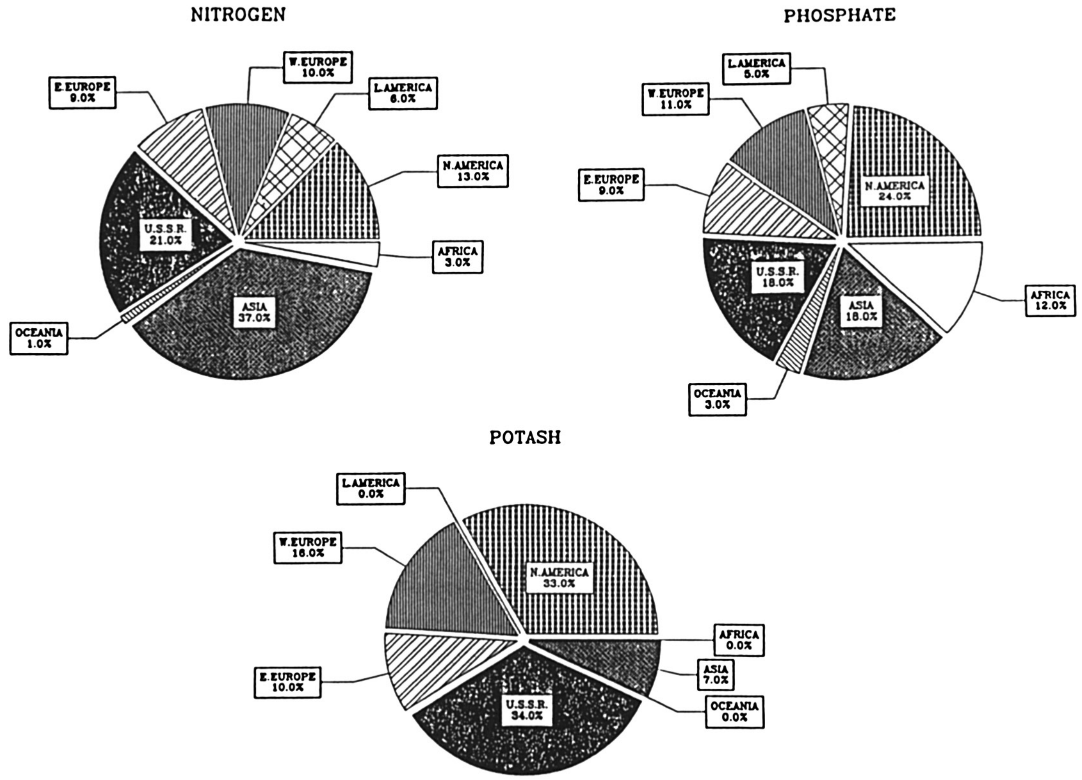
## FIGURE 11

## REGIONAL SHARES OF WORLD FERTILIZER USE, 1995



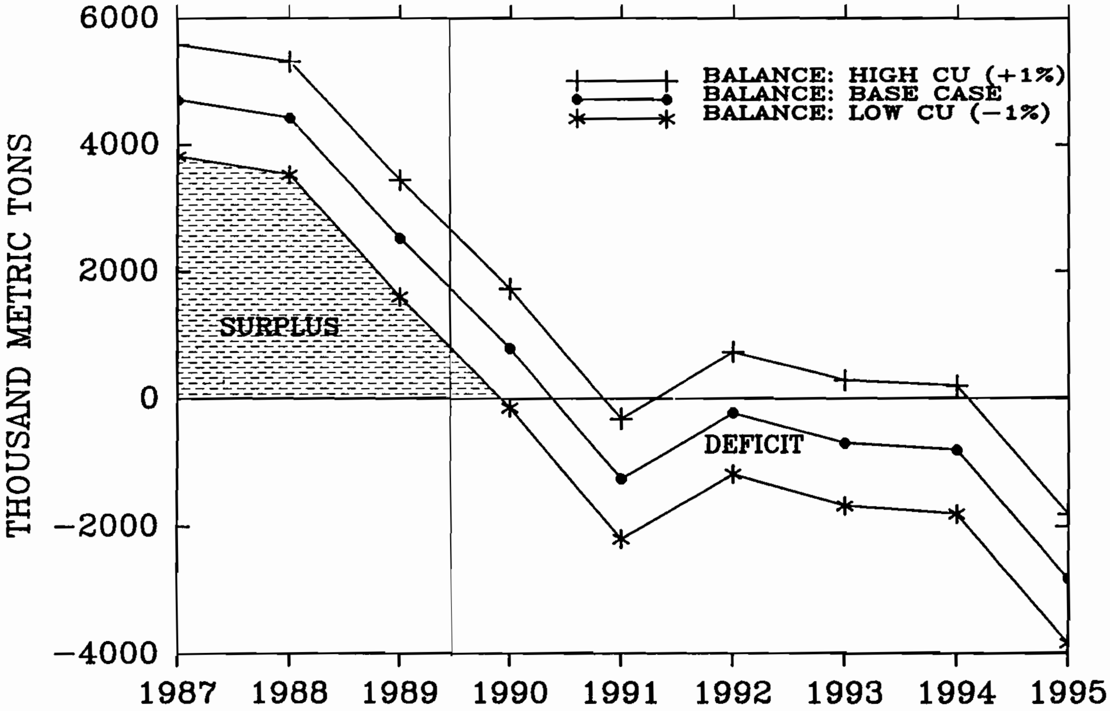
## FIGURE 12

## REGIONAL SHARES OF WORLD FERTILIZER PRODUCTION, 1995
N/P205/K20



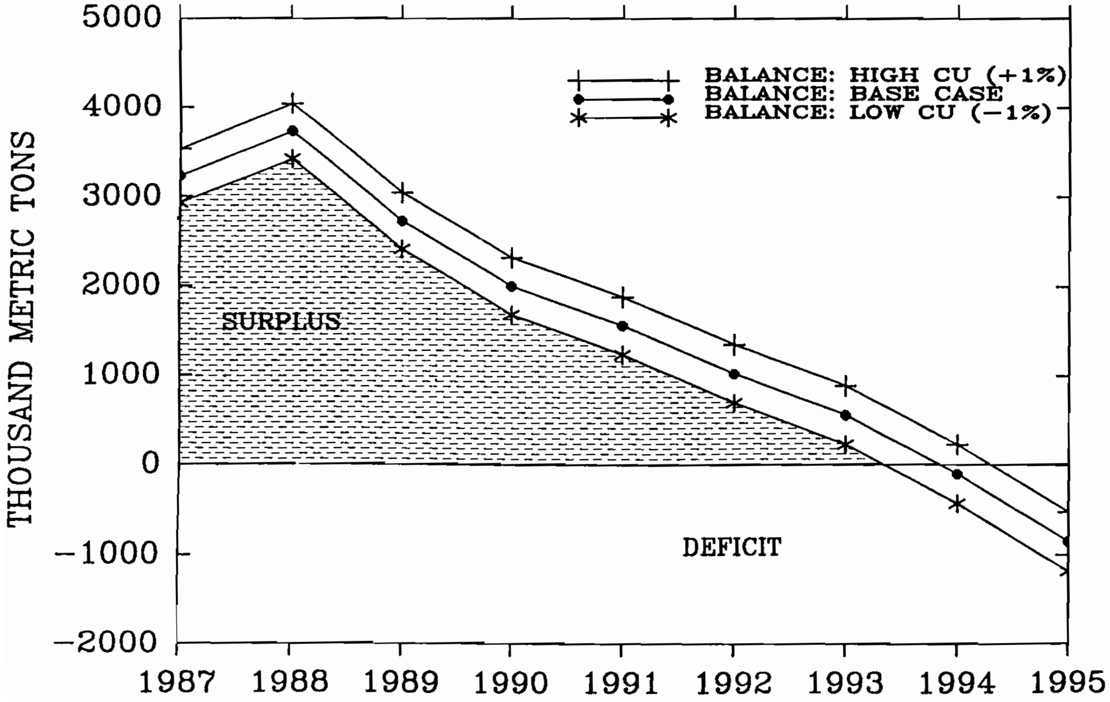
## FIGURE 13

GLOBAL NITROGEN: PROJECTED SUPPLY – DEMAND BALANCE (1987–1995)



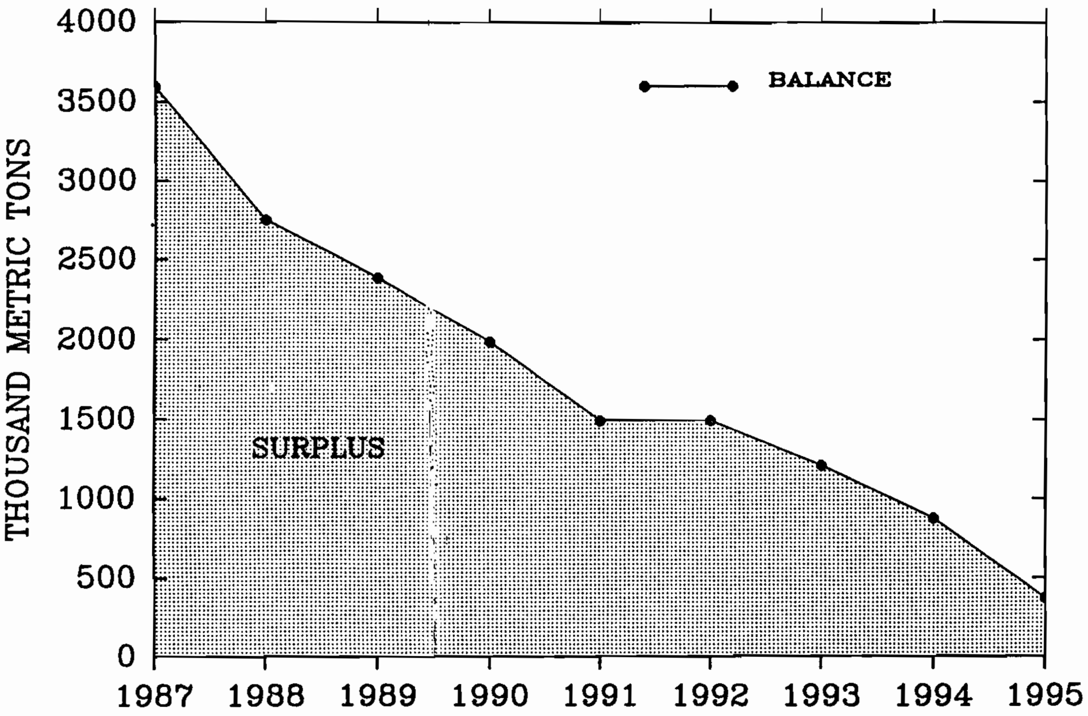
## FIGURE 14

PHOSPHATE: PROJECTED GLOBAL SUPPLY–DEMAND BALANCES, 1987–95

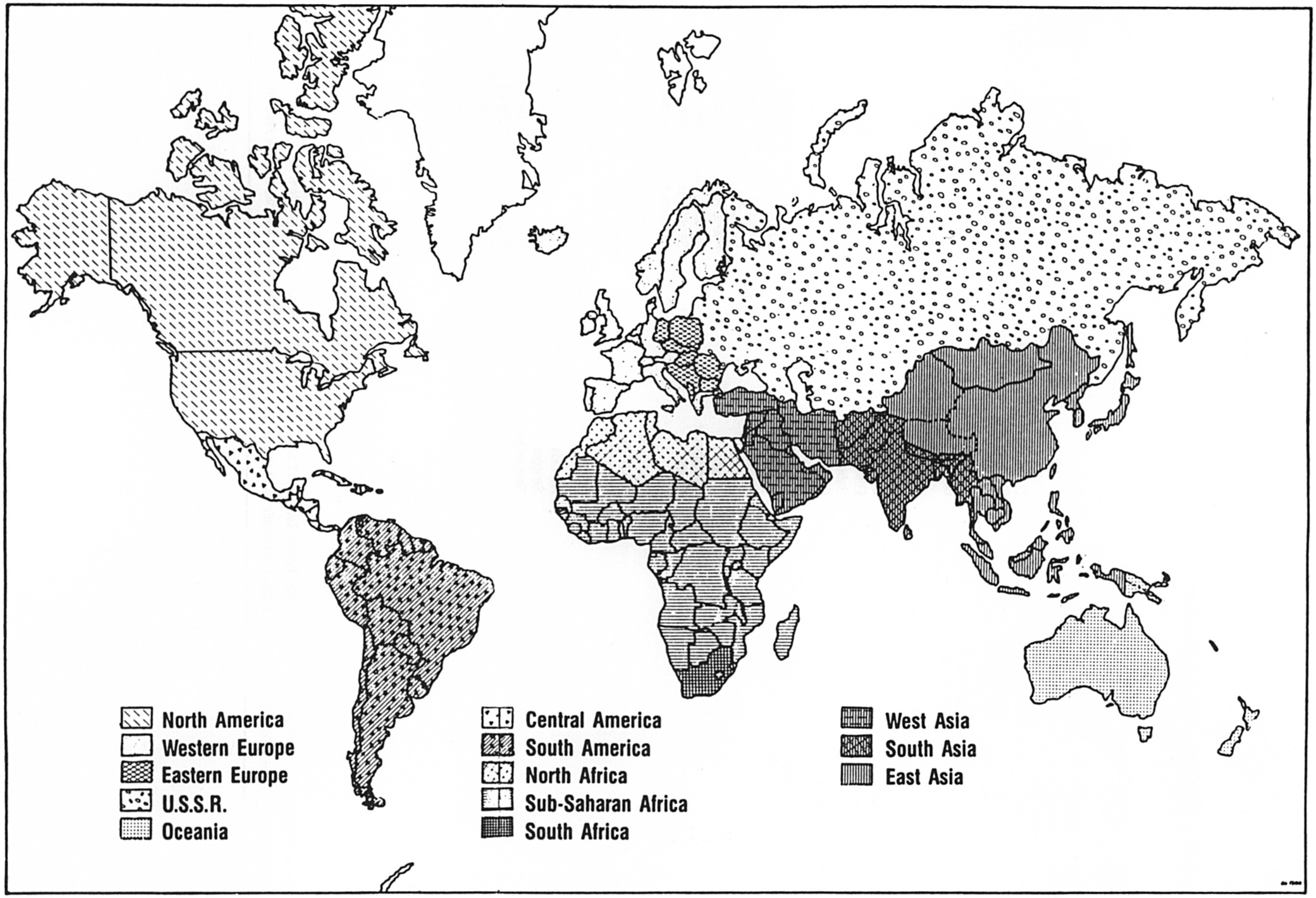


## FIGURE 15

GLOBAL POTASH: PROJECTED SUPPLY – DEMAND BALANCE (1987–1995)



## FIGURE 16



Map 1. Regional Classification.

# Appendix A
# Regional Classification

## Part I. IFDC Regional Classification

**North America**
- Canada
- United States

**Western Europe**
- Austria
- Belgium-Lux
- Denmark
- Finland
- France
- Germany FR
- Greece
- Iceland
- Ireland
- Italy
- Malta
- Netherlands
- Norway
- Portugal
- Spain
- Sweden
- Switzerland
- United Kingdom

**Eastern Europe**
- Albania
- Bulgaria
- Czechoslovakia
- Germany DR
- Hungary
- Poland
- Romania
- Yugoslavia

**U.S.S.R.**
- U.S.S.R.

**Africa**
- *Sub-Saharan Africa*
  - Angola
  - Benin
  - Botswana
  - Burkina Faso
  - Burundi
  - Cameroon
  - Central African Republic
  - Chad
  - Congo
  - Cote d'Ivoire
  - Ethiopia
  - Gabon
  - Gambia
  - Ghana
  - Guinea Bissau
  - Guinea
  - Kenya
  - Lesotho
  - Liberia
  - Madagascar
  - Malawi
  - Mali
  - Mauritania
  - Mauritius
  - Mozambique
  - Niger
  - Nigeria
  - Rwanda
  - Senegal
  - Seychelles
  - Sierra Leone
  - Somalia
  - Sudan
  - Swaziland
  - Tanzania
  - Togo
  - Uganda
  - Zaire
  - Zambia
  - Zimbabwe
- *South Africa*
  - Republic of South Africa
- *North Africa*
  - Algeria
  - Egypt
  - Libya
  - Morocco
  - Tunisia

**Latin America**
- *Central America*
  - Bahamas
  - Barbados
  - Belize
  - Bermuda
  - Costa Rica
  - Cuba
  - Dominica
  - Dominican Republic
  - El Salvador
  - Guadeloupe
  - Guatemala
  - Haiti
  - Honduras
  - Jamaica
  - Martinique
  - Mexico
  - Nicaragua
  - Panama
  - Puerto Rico
  - St. Chris, etc.
  - Saint Lucia
  - St. Vincent
  - Trinidad, etc.
  - Virgin Islands
- *South America*
  - Argentina
  - Bolivia
  - Brazil
  - Chile
  - Colombia
  - Ecuador
  - French Guiana
  - Guyana
  - Paraguay
  - Peru
  - Suriname
  - Uruguay
  - Venezuela

**Asia**
- *West Asia*
  - Bahrain
  - Cyprus
  - Iran
  - Iraq
  - Israel
  - Jordan
  - Kuwait
  - Lebanon
  - Oman
  - Qatar
  - Saudi Arabia
  - Syria
  - Turkey
  - United Arab Emirates
- *South Asia*
  - Afghanistan
  - Bangladesh
  - Bhutan
  - Burma
  - India
  - Nepal
  - Pakistan
  - Sri Lanka
- *East Asia*
  - China
  - Indonesia
  - Japan
  - Kampuchea
  - Laos
  - Malaysia
  - Mongolia
  - Korea, DPR
  - Korea, Republic
  - Philippines
  - Singapore
  - Taiwan
  - Thailand
  - Viet Nam

**Oceania**
- Australia
- New Zealand
- Papus New Guinea
- Samoa
- Fiji

Developing Countries—Includes North America, Western Europe, Eastenr Europe, U.S.S.R., Japan, Israel, South Africa, Australia, and New Zealand.

Developing Countries—Includes Latin America, Asia (except Japan and Israel), Africa (except South Africa), and Oceania (except Australia and New Zealand).

# Tuesday, October 31, 1989

## Session II
## Moderator:

## James Brown

## Upgrading a Phosphate Mining Phosphoric Acid Complex by Recovering Phosphate Rock from Waste Phosphate Slimes

*Igor Kotlarevsky*
**S.C.P.A.-France**

### *THE RECOVERY OF FINE PARTICLES OF PHOSPHATE ROCK FROM SLIMES IN SENEGAL*

1. *SENEGAL* is a small country located on the West Coast of Africa. In fact, it is the most Western state of Africa.

It has a population of 7 to 8 million and the income per capita is presently around 380 US D per year.

Senegal has very limited resources. There are basically four main sectors of activity: ground nut, fishing, tourism and phosphates.

2. *Phosphate mining* started in the 60's with a Joint-Venture between Senegal, France and the American company I.M.C.C. which still keeps an 11% share in the mining company called C.S.P.T. (SENEGALESE COMPANY for TAIBA PHOSPHATE). Taiba phosphate rock has been exported since the creation of C.S.P.T. at the rate 1.5 to 2 million Metric Tons per year. This rock is of very high grade and very suitable for acid production (see analysis in Table 1).

In 1976 arose the idea of building a large phosphoric acid plant in Senegal which would be located close to the mine in order to absorb the "trash" from the mine. By "trash" I mean the $P_2O_5$ values which cannot be exported. A new company was created: I.C.S. (CHEMICAL INDUSTRIES OF SENEGAL) which has shareholders from various governments: Senegal, Republic of Ivory Coast, Cameroun, India and the French company S.C.P.A.

In 1984 the phosphoric acid plant started up with a nameplate capacity of 240,000 MT per year $P_2O_5$ and since then the plant has been consistently producing around 180-190,000 MT $P_2O_5$ per year.

The production of the plant is exported as clarified acid to India and as solid fertilizer to surrounding Western African countries, very little being consumed in Senegal.

3. *Description of the mine and slimes:*

Phosphate rock mining in Senegal is performed like in Florida with standard equipment: overburden is removed with bucket wheel excavator, matrix is extracted with walking draglines. The matrix is carried with very large trucks to a first screening unit where flint stones are removed and matrix is slurrified to be piped to the beneficiation plant. In the beneficiation plant, there is a washing unit with desliming, flotation and drying. The slimes are obtained by cycloning the slurry. The fraction below 40 microns is discharged in slimes ponds where water is recovered.

It happens in Senegal—as it happens frequently with slimes from phosphate rock—that the slimes contain a certain amount of $P_2O_5$ which is lost.

In Senegal the proportion is probably larger than in other deposits. About 40% of the $P_2O_5$ contained in the matrix is lost in the fine fraction.

This is why the idea came to establish a process for the recovery of part of this lost $P_2O_5$. This 40% figure may be misleading because in fact a portion of this $P_2O_5$ cannot be recovered easily as it is $P_2O_5$ under the form of iron and aluminum phosphates. But a 10 to 20% figure is feasible. This is the starting point of our process.

4. *The process:*

I am not going to describe the process in many details because it has been done in several international mining meetings (see references at the end).

Basically the process consists of an additional desliming step with a lower cutting point. Cyclones perform a separation by size of the particles in slurries. The coarse particles leave the cyclones by the underflow, the fine particles go to the overflow of the cyclone.

In our process, we decided—in agreement with the chemical distribution of the $P_2O_5$—that a 14 microns cutting would represent the ideal for a good recovery of tricalcium phosphate, leaving the major part of the Iron and Aluminum in the fine slimes.

It is known that the smaller the cutting point, the smaller the cyclone. We have to utilize 2" cyclones which are called micro-hydro-cyclones. And obviously as the total flow is large, a large number is needed.

Usually the 2″ cyclones are combined in clusters of 16 units, and these clusters are again combined in "super-clusters" of 9.

That means that we are using packs of 144 cyclones. Our process consists of 3 steps of cycloning. The first step with 288 cyclones makes a rough cutting, the second step with 144 cyclones makes a washing of the recovered fine phosphate rock particles in order to remove some of the remaining clay and the third step with 144 cyclones performs the concentration of the fine rock in order to feed the phosphoric acid reactor with as little water as possible, but still keeping a pumpable slurry (see table 1 for analysis).

In addition to the desliming section, this plant includes a water recovery section which is necessary for the mine operation.

5. *Two year operating experience:*

A pilot plant was built in 1986 with a financing from the World Bank. The plant, with a capacity of 20 MT per hour, started in June 1987. We have today more than two years experience. The plant has been consistently running at capacity.

There were some fears and some concerns from our money lenders which were willing to reduce the burden on the shoulders of the local operators.

But I cannot mention today one major drawback of the plant. The main areas of concern were the following:

a) wear of the cyclones

b) plugging or blocking of the cyclones

c) difficulties in the phosphoric acid plant

d) quality of the phosacid

*NOTHING HAPPENED:*

1. the cyclones are in strong polyurethane and have not sufferred any abrasion. There has been some normal wear in pumps.

2. a grid protects each cluster of 16 cyclones and a monthly cleaning of the grid prevents any plugging.

3. at the rate of 20 MT/H the $P_2O_5$ ratio of fine phosphate to standard Taiba rock in the phosphoric reactor is around 14%. Nothing is felt. Iron and Aluminum are obviously higher in the acid but not significantly (see Table 1 for analysis).

What about recoveries? We are recovering about 25% of the $P_2O_5$ contained in the slimes.

The major difference between our preliminary studies and the unit is in the presence of silica. We are recovering more silica than forecasted. The fine rock recovered contains about 15% $SiO_2$ instead of 5 to 6% in the project. This is not harmful except for wear of pumps. It originates probably from the matrix which contains more silica today than when the preliminary tests were performed.

**TABLE 1**
**ANALYSIS OF: 1° TAIBA ROCK**
**2° RECOVERED FINES EX-SLIMES**
**3° PHOSPHORIC ACID**

**ALL SAMPLES TAKEN DURING THE SAME PERIOD (AUGUST 1988)**

| | Rock | Slimes | 54% $P_2O_5$ Acid |
|---|---|---|---|
| $P_2O_5$ | 36.7 | 30.1 | 54 |
| $SiO_2$ | 5.3 | 15.6 | — |
| $CaO$ | 49.3 | 40.7 | 1.7 |
| $Al_2O_3$ | 1.2 | 3.2 | 2.0 |
| Fe 203 | 0.9 | 2.0 | 1.5 |
| $I + A/P_2O_5$ | 0.056 | 0.173 | |
| SO4 | — | — | 2.9 |
| SP GR | — | — | 1.724 |
| Solids | — | — | 1.04 |
| Moisture | 9.6 | 50.3 | |

A laboratory study has been launched to check if flotation can be performed to remove some of the silica and hopefully some iron and aluminum.

There have been no operating problems and I can say that normally this plant is "forgotten" by the operators. It runs by itself (see Table 2 for production in 1987, 1988 and 1989).

In reference to costs, we are roughly spending per MT of recovered phosphate

1.5 US $ for manpower

1.0 US $ for floculant (for water recovery)

4.5 US $ for electricity

3.0 US $ for maintenance and spare parts

**TABLE 2**
**PRODUCTION OF FINE ROCK RECOVERED IN MT/MONTH**

| | 1987 | 1988 | 1989 |
|---|---|---|---|
| Jan | 0 | 3,600 | 1,700 |
| Feb | 0 | 6,400 | 9,500 |
| Mar | 0 | 9,600 | 9,200 |
| Apr | 0 | 11,700 | 6,200 |
| May | 0 | 11,700 | 6,900 |
| Jun | SU–NA | 7,500 | 7,700 |
| Jul | NA | 10,800 | AT |
| Aug | NA | 8,400 | AT |
| Sep | 4,300 | 2,800 | 8,100 |
| Oct | 5,500 | 4,100 | — |
| Nov | NA | 5,000 | — |
| Dec | NA | 4,700 | — |
| Total | 36,183 | 86,400 | — |

AT means annual turnaround
SU means start up
NA means not available

That makes a total of 10 US $/MT of fine rock as a cash cost and this includes the recovery of 10 T of water per ton of fine rock recovered.

Capital spending was in 1986/1987 around 6.0 millions US $. This includes 2 million US $ for water recovery and 2 million US $ for a preliminary thickener needed at the mine, leaving 2 million US $ for the cycloning and utilities.

6. *Future plans:*

We have tested in our phosacid pilot plant the effect of adding more fines in the phosphoric acid reactor. Our conclusion is that we can add up to 30% of the total $P_2O_5$ as fine rock without hurting filtration rates and $P_2O_5$ losses.

We are therefore looking for money to build a new unit for handling more slimes and recovering more $P_2O_5$ from the slimes presently discharged in ponds.

As a conclusion, I can say that this plant has been troublefree for the last two years. It has allowed Senegal to export 100.000 MT/year of additional standard phosphate rock representing 4 million U.S. $ of revenues to the country and it has saved I.C.S. about 1 million U.S. $ per year in rock purchases.

A doubling of the plant will double these figures.

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## From Catastrophe to Opportunity

*(Converting A Flooded Potash Mine To Solution Mining)*

*R. C. Smith*

**Potash Company of America—Canada**

I'd like to start by reviewing the history of PCA's mine in Saskatchewan, including the water inflow and our efforts to control it. Then I'll describe the solution mine we completed last spring and tell you about its products and how they will benefit the industry.

PCA was the first potash company to develop a mine in Saskatchewan. As you know, pioneers often run into unexpected problems and we were no exception. The mine started producing in 1958, with a design capacity of 350,000 tons of standard grade muriate per year. It operated for only 11 months before water entering the shaft forced it to shut down. It was down for 6 years, as we sealed the shaft leak and redesigned the mill to permit the production of Granular and Coarse grades by flotation. We also raised the capacity to 500,000 tons per year.

Capacity was gradually expanded to 1,154,000 tons by 1984. In spite of being the smallest mine in Saskatchewan, it was very efficient and consistently profitable. Its market niche was high quality and attention to customer needs.

In 1975, we mined into an area where the salt/potash bed, which overlies the potash ore, suddenly ended, as did the ore itself. A brine inflow of about 1 gallon per minute was encountered at that point.

In a matter of weeks, about a dozen separate brine inflows—totaling mroe than 300 gallons per minute—were entering the mine from the roof in this area.

Experts were brought in; the roof was grouted and concrete pillars were poured to support it. Over a period of six months the brine inflow was reduced to about 20 gallons per minute, where it remained unchanged for the next 10 years.

In January 1986, brine began to collect about a mile from the original inflow area. Despite difficulties because of considerable floor heave and roof collapse, we were able to trace the inflow to the exact point where brine had been encountered 10 years earlier.

As soon as we determined the source of the brine, we undertook an elaborate program to grout off the brine inflow in the same general manner as we had done earlier. We believed that the brine was moving horizontally through the Dawson Bay formation, a porous limestone formation above the mining horizon.

The plan was to drill and case holes from the mine workings into the Dawson Bay formation. Then, while relieving brine from some of these pipes, we would pump cement and chemical grouts through others, blocking off the flow of incoming brine.

About 160 holes were drilled and extensive data on pressure and flow were collected. We found pressures as high as 1720 psi and flows of more than 300 gallons/minute from individual drill holes. Analysis of this data indicated that the brine was not moving through the Dawson Bay as we had thought, but was coming vertically—through cracked formations—from the Blairmore formation about 2800 feet above.

The Blairmore formation contains unlimited quantities of brackish water not brine. Water, of course, is the real enemy of potash mines since it will dissolve both salt and potash.

We knew that we could not stop an inflow from the Blairmore with grouting; so we decided to use the grouting program as a delaying tactic while we fell back to our next line of defense: concrete plugs in the underground workings.

Engineering studies indicated that carefully constructed concrete plugs, with thorough grouting of the ground around them, would be able to hold back the brine and leave the balance of the mine dry. In our case, 14 plugs would be required, each about 90 feet long, 30 feet wide and 25 feet high. Construction of the first plug began in October 1986; but just before Christmas it became apparent that the inflow had begun to increase at a substantially higher rate.

The inflow reached 1500 IGPM by New Year's of 1987. It became clear that we did not have time to finish the plugs.

All during this period, we were pumping brine 3 miles from the inflow area to the shafts, and then to surface. Power lines and pipelines had to be run down the shafts, as well as extra air to cool the pump motors. By the time we decided to stop the plug project, we had 140 people working on the water problem and had spent nearly $13 million on it.

I'm sure you can imagine how stressful it was for everyone. We were certainly glad to have the backing of Rio Algom Limited, our new parent company, who had purchased PCA shortly before the flooding started. They provided the money, and many of their top management and technical people came to the mine with encouragement and valuable advice.

Mining ceased on the 3rd of February, and we brought everything of value (about $17,000,000 worth of equipment) out of the mine before water reached the shafts. To preserve the shafts, in case we decided to use them again for conventional mining, we installed 50-foot thick concrete plugs in the limestone about 150 feet above the mining level.

In the meantime, our marketing group had made arrangements to purchase potash so as to ensure continued availability to our customers.

PCA has always been fortunate to have a first-class work force in both supervisory and hourly ranks. For those of you interested in motivation and human resources, we saw some interesting developments while we were fighting the water inflow.

1. Absenteeism, which had been a minor problem, completely disappeared once it became clear the water inflow was serious.
2. When we had to switch our most senior supervisors to the water problem, operating supervision was severely reduced. Hourly employees readily picked up the slack. Work normally done by supervisors, such as requisitioning parts and notifying maintenance of needed repairs, was done almost entirely by hourly-paid employees.
3. The mining machines continued to produce even though we had to strip them of the most experienced miners. The mill continued to operate, even though a large part of the mill maintenance force was sent underground. Production targets were met each month in 1986.
4. In spite of extremely difficult working conditions in the water hole area, and an influx of 140 new, very green employees on top of the normal underground workforce of about 90, there was *not a single lost time injury* in 1986. In fact, the mine won the Ryan Trophy as the safest mine in Canada, in its category—an almost unbelievable achievement.

We had been evaluating solution mining, among other alternatives, for some time. In the spring of 1986, while we were still fighting the water inflow, we had set up a small-scale operation where we passed plant brine through a couple of children's swimming pools, to see if we could produce potash by cold weather crystallization. We also carried out extensive dissolving tests on blocks of ore representing the mine walls.

In the spring of 1987, we completed feasibility studies on re-developing the mine using either conventional or solution mining. The studies indicated that solution mining was the preferred alternative.

A large pilot plant was built in the fall of 1987, at a capital cost of about $2 million. We put it into operation in the spring of 1988. It consisted of one recovery well with a pump located below the brine level about 900′ below surface, a crystallization pond, and one injection well. The warm brine from the recovery well was pumped about 3 miles through 12″ polyethylene pipe, to a 9-acre crystallization pond. Here the brine was cooled, precipitating potash in the bottom of the pond. The cold brine was picked up at the other end of the pond and injected back into the mine. As it travelled through the mine, the brine dissolved more potash and the process was repeated. The precipitated potash was picked up from the pond by a bucket-wheel dredge and pumped to the mill, where it was processed using normal potash milling equipment.

Despite many problems in building and operating the pilot plant, the operation was completely successful, and we produced enough potash to recover most of the money spent to build and operate it. Test shipments of this potash were made to a number of customers, who were well pleased with it.

In August 1988 we obtained approval to construct a commercial scale solution mine at Saskatoon. Work began as soon as environmental and other governmental approvals could be obtained, and proceeded through the fall and winter and into the spring of this year.

The initial capacity of the solution mine was selected on the basis of market forecasts, not technical considerations. We are currently using only a fraction of the underground workings, so the output can be expanded substantially when the market demands it.

The total investment to convert to solution mining at Saskatoon is now approximately $25 million in Canadian funds. Converting a flooded mine into a solution mine has been likened to turning a lemon into lemonade. If this is the case, Rio Algom and the Canadian Imperial Bank of Commerce certainly provided the sugar.

The pilot plant was built by a small number of former PCA employees under direction of our own skeleton supervisory and engineering staff. We decided to go the same way with the commercial scale plant.

The decision to use our own laid off people helped ensure good employee relations, but it was primarily a matter of long-term economics.

1. We knew that we had hard working, trainable people, and that they could out-produce construction contractors who would have cost us up to twice as much per hour.
2. We felt that, if the operation was built by the people who would ultimately operate it, they would take extra care to ensure that they didn't have to go back and fix it later.
3. While we had no legal requirement, we felt that our people deserved it after years of loyal service.

Thus, mining machine operators, who normally worked 3,400 feet below ground at 80° F, found themselves operating the dredges required to deepen our old brine pond. The idea was to develop a pond to a uniform depth of 7 feet over an area of 130 acres. Apart from the pilot operation, none of us had ever operated—or even seen—a dredge before. In addition, the work was done during a Saskatchewan winter when temperatures of 40 below are not uncommon.

Mill operators and maintenance crews fused and buried the 32-inch polyethylene pipeline from the recovery wells, and the 24-inch lines to the injection wells. The only non-PCA employees involved were the drilling crews who drilled and cased the wells.

Environmental considerations required special attention. The pipelines ran over miles of farmland to connect the wells and the pond. After extensive discussions with Saskatchewan Environment and Public Safety, and other government agencies, we decided to use high density polyethylene pipe and to bury it under at least two feet of soil, so as to restrict movement. Even though the chance of leak in this type of line is negligible, we buried a 6-inch polyethylene weeping tile at the bottom of the pipe trench, connecting it to concrete collecting chambers at low points in the line. In this way, any leaks into the weeping tile can be sampled. Where there was sand or gravel, we enclosed both the pipeline and the weeping tile in a fabric liner. In addition, we further encased the polyethylene pipe in steel pipe wherever it crossed a creek.

To check on possible brine leakage, the pipelines are surveyed frequently using electromagnetic conductivity instruments which can locate brine underground. No brine leaks have occurred since we started up the commercial plant. With hindsight it may be that the weeping tile, collecting chambers, fabric liners and so on, were probably environmental overkill.

Brine pumping from the mine started in January and increased steadily throughout the spring. There have been problems, of course. One of our first was that waves developed in the brine pond and destroyed the brine feed header during the spring.

During the early stages, we found that a small amount of clay had become mixed with the bottom two feet of potash in the pond. This was probably the result of turbulence caused by wind. Fortunately, there were a number of settling tanks available in the mill, and we were able to modify the system to settle out this fine clay and get back to a good white colour.

Potash produced by solution mining is white, of course, because it doesn't contain the iron oxide contaminant which causes the red colour of conventionally mined potash. The amount of insolubles, primarily clay, is also lower than for conventionally mined product. For example, when our Saskatoon mine was using conventional mining, the insoluble content was about 0.7%. It is now about 0.05% and will probably drop further as time goes on.

We plan to produce a product grading 62% $K_2O$, or about 98% KCl. This will allow our customers to gain an important advantage by formulating to this concentration.

Production costs are, of course, of vital importance to us. We feel that we will be able to compete with anyone in North America.

Solution mining benefits from the need for fewer employees. There are no underground operations, of course, and milling can be simplified by eliminating more than half of the circuits.

While I certainly hope that no one else will have reason to convert a conventional potash mine to solution mining, I'd like to share with you some of the requirements which we feel are essential for this conversion.

1. A large contact area is needed underground. After 22 years, PCA has over 400 miles of drifts available. In addition to the potash in the mining level, there is another potash-rich bed a few feet above the mining level. PCA conventional mining utilized a very conservative extraction ratio, leaving well over 70% of the ore untouched. This will become the feed for the solution mine. If a large part of the mined-out area had collapsed or even closed up, it would have made it much tougher to establish flows and to obtain good contact area. Fortunately, the system used by PCA led to very little collapse in old workings.
2. PCA has negligible amounts of carnallite in its ore. The presence of carnallite—an extremely soluble material which does not precipitate out at low temperatures—would complicate the process and might even make it unworkable.
3. The grade of the ore in contact with the brine

must be at least 15% $K_2O$. Potash ore is a mixture of salt, potash and clay; in order to dissolve it and remove the potash, there must be continuing passages into the ore; and these passages will not develop if the ore grade is low. Ore grades at Saskatoon are in the 25% range.

4. A cold climate is needed and Saskatchewan, as you know, has extremely cold winters. A mine in New Mexico could not use this system.
5. The temperature of the ore body must be well above the winter temperature. Again, mines with cooler ore bodies, such as those in New Brunswick, could not likely be converted to solution mining. Heavy rainfall would obviously be a serious problem as well.
6. A suitable crystallization pond is essential. If it were necessary to line the very large ponds which we believe are needed, the project cost would escalate and environmental problems would multiply. PCA has a large natural pond available.

The challenge we face now is to ensure that the quality of our product is the best in the industry, a position we believe we held before the flooding.

It would take me at least ten more minutes to list those companies, consultants and individuals who have given us ideas and information to put together this project. I won't do that, but I think they can all take satisfaction that the mine is coming back into production, providing jobs, paying taxes, producing profits, and supplying a high quality raw material.

PCA looks forward to serving the needs of the fertilizer industry in the years ahead.

# New Developments in the Chinese Fertilizer Industry

*K. M. Constant*
**The World Bank**

## *I. INTRODUCTION*

The Chinese have always called themselves descendants of Huang Di and Yan Di. According to legend, Yan Di was a bull-headed figure who first taught his people farming skills. Though this is an obvious fairy tale, the fact that 1.1 billion people hold a "farming god" in high esteem as one of their ancestors shows the importance agriculture has in the country's history.

In 208 BC, a county magistrate once offered his ideas on how to manage state affairs to the later first emperor of the Western Han Dynasty, Liu Bang. He said to Liu, "The most important thing for a country is its people and the most important thing for these people is food". This idea has since then not lost any of its significance.

The importance of food supply has been one of the top issues over a long time and has been one of the most dominating factors in policy-making after the establishment of the People's Republic of China in 1949. In 1958, China's grain output totalled 250 million tons, an increase of 35% over the previous year. The fact that China managed to feed one fourth of the world's population with only 7% of the world's arable land won international recognition. At that time, about 127 million farming households (99% of the total) were organized into more than 26,500 communes across the country, which were divided into brigades, and brigades into production teams. The production unit, consisting of about 20-30 households, was generally the basic producing and accounting unit.

Subsequent problems experienced later on particularly in distribution, production planning and the lack of individual incentives, resulted in sweeping changes in rural policies in 1978, which were aimed at encouraging the development of a more diversified rural economy, raising State purchasing prices of farm produce, reviving free markets and expanding the decision-making power of production teams in their own affairs.

By raising production enthusiasm of individual farmers to an unprecedented extent, the new system led to dramatic grain increases and sustained overall economic growth in the following years.

During the Sixth Five-Year-Plan (1980-1985) period, agricultural production went up at an average annual rate of 8.1 percent. From 1979 to 1987, national grain output increased from 300 million tons to 400 million tons; the annual output of cotton increased from 2 million tons to 4 million.

However, recent years have seen a slowing down of the agricultural growth rate as new problems emerged. First, State investment in capital construction projects in agriculture has reduced. Second, more arable land has been eroded by expanding urban areas, industries and even farmers' housing projects. Third, as inflation in the country soars, a number of farmers have changed to cash crops, causing low growth rate and even decrease in the country's grain output. Although the State has raised the purchasing prices of some farm products in face of the rising inflation, such efforts have not had the expected impact.

Today's agriculture in China employs some 190 million farm families and accounts for about 34% of the country's GNP. It provides reasonable self-sufficiency in the basic food requirements of its population, which presently amounts to around 1.1 billion people and is growing at a rate of 15 million people a year, despite the scarcity of arable land.

The whole nation seems now to have awakened from the blind optimism that once prevailed across the country after the bumper harvest in 1984. The Chinese Government has re-affirmed its policy that agriculture will remain the foundation of its economic development, with grain production being the key to a prosperous agriculture industry. Consequently, there is an eminent need for further development of a nutrient-balanced high-grade fertilizer industry, but also continued demand for fertilizer imports.

## *II. THE DEVELOPMENT OF THE CHINESE FERTILIZER INDUSTRY*

### The Nitrogen Subsector

In 1949, China's total fertilizer production amounted to about 5,700 tons of ammonium sulfate. A rapid expansion of the local nitrogenous fertilizer industry started in the late 1950s based on small ammonium bicarbonate (ABC, 17%N) and aqueous ammonia (12-16%N) plants. Although using outdated coal gasification technology, those small plants dispersed across the country provided a much needed resource for nitrogen. The plants were built at a fast rate with little attention to availability and quality of raw materials, adequacy of processes, equipment and training. In the mid 1960's, considerable effort was made to improve the technology used in those plants, to develop standard designs and plant scale, to set standards for product quality and train personnel and management. Until about 1976, most of the installed production capacity was in about 1,200 small and medium size nitrogenous fertilizer plants. Typically, most of the small plants use anthracite as feedstock and an intermittent air blow/steam gasification fixed-bed process. Modified versions use coke, fuel oil or natural gas as feedstock. Their products are generally ammonium bicarbonate and aqueous ammonia; capacities range from 5,000-20,000 tpy anhydrous $NH_3$ and about 20,000-80,000 tpy ABC. Only few plants produce ammonium chloride or ammonium nitrate.

Since the mid 1970s the development of the nitrogenous fertilizer industry has been based on a "two-legged" approach: (i) imports of large ammonia/urea plants using up-to-date international technology; and (ii) to a lesser extent, installation of indigenous medium sized plants (typically 40,000-60,000 tpy ammonia and 160,000-200,000 tpy ABC). Although these medium size plants incorporated improvements in design over second generation plants built in the late 1960s, they continued to rely on fairly energy intensive coal-based technology. Since 1974, China built 16 ammonia/urea plants from American, Japanese and European suppliers. These plants were designed to produce 1,000 tpd of ammonia and 1,650 tpd urea and most of them use natural gas as feedstock. Today, five of these plants are based on naphtha and three on fuel oil; the 17th ammonia plant, which is part of a recently commissioned nitrophosphate complex, uses imported coal gasification technology. Two more plants are in the commissioning stage. These plants were locally financed, use overseas technologies, but attempted to maximize local inputs in terms of engineering services and equipment. They are expected to be in full commercial production by 1990.

Regardless their high energy consumption, small size fertilizer plants are still the main source of nutrient, contributing almost one half of China's total nitrogenous fertilizer output of roughly 13 million tpy of nitrogen, whereas the 54 medium size plants supply about one quarter.

During the late 1970s the government started a large program to reduce energy consumption in small and medium size plants and improve the stability and effectiveness of their products and focused mainly on two aspects: (i) technical assistance and development programs carried out jointly by research institutes and the fertilizer industry, and (ii) an organized exchange of information, know-how and personnel between the enterprises to reduce the large variation of about 20% in energy consumption in the fertilizer sector and improve quality of ABC. The improvement would mainly come from better material preparation, improvement in operating procedures and maintenance, and training of workers and managers.

### *THE PHOSPHATE SUBSECTOR*

It was not until 1955 that commercial production of phosphatic fertilizers started at a level of 1,400 tpy in China. By now the number of indigenous small size phosphatic fertilizer plants has reached about 700. The products are mainly single superphosphate (SSP) and fused calcium magnesium phosphate (CMP).

The Government has realized the importance of the phosphate subsector and recent indications are that all available local production facilities have been put into full operation to meet the growing $P_2O_5$ demand, despite the fact that the majority of the plants are small and produce low grade products, mainly SSP.

### *THE POTASH SUBSECTOR*

Local production of potash has grown steadily, but is still insigificant at a level of 25,000-40,000 tpy of $K_2O$.

### *NUTRIENT APPLICATION RATIOS*

While China has become the third largest user of chemical fertilizers and the largest consumer of nitrogen in the world, its average fertilizer application rate (in 1986: 176.2 kg of nutrient per ha of arable land) is still only about one third of that in neighboring countries, such as Japan or Korea. This implies that there is still a large potential for increased fertilizer use, particularly for phosphates and potash due the prevailing imbalanced application of $N:P_2O_5:K_2O$.

## *III. WORLD BANK FINANCED FERTILIZER PROJECTS IN CHINA*

After a number of years of virtual isolation from technological and scientific developments abroad, China embraced in the 1970s a policy of opening to the outside world through which the country hoped to obtain access to some of the professional and technological advances it had missed. In the early 1980's the Government of China approached the Bank to co-finance the first Bank operation in the fertilizer sector, the Fertilizer Rehabilitation and Energy Saving Project, which was subsequently followed by three other fertilizer projects, all of which are now under implementation. Several requests for additional projects are being evaluated.

In support of China's efforts to establish an efficient fertilizer sector, the Bank's major objectives in the sector are to provide:

(a) advice on policy measures relevant to the improvement of sectoral efficiency, particularly in fertilizer pricing and allocation, investment planning, information management, and management reforms; and

(b) financial and technical assistance in modernizing existing fertilizer production facilities, building new capacities, particularly for phosphate and potash fertilizers to facilitate adjustments of the nutrient imbalance, and selecting appropriate technologies; and

(c) institution building and training.

### *1. THE FERTILIZER REHABILITATION AND ENERGY SAVING PROJECT*

| | |
|---|---|
| **Beneficiaries:** | Cangzhou Chemical Fertilizer Company (CCFC), Hebei<br>Liaohe Chemical Fertilizer Company (LCFC), Liaoning<br>Luzhou Natural Gas Chemical Company (LNGCC), Sichuan<br>Yunnan Natural Gas Chemical Company (YNGCC), Yunnan<br>Nanjing Chemical Industry Company (NCIC), Jiangsu<br>China Fertilizer Development Center (CFDC), Shanghai |
| **Project Cost:** | US$ 186.6 million equivalent (US$ 122.7 million equivalent in foreign exchange) |
| **Bank Loan:** | US$ 97.0 equivalent over 20 years, including five years of grace, at standard variable interest rate |
| **Components** | (a) Rehabilitation, modernization and energy saving modifications in the fertilizer plants of the five companies and training of their staff;<br>(b) equipment, data processing facilities and training to strengthen the research and design capabilities of CFDC and its eight member institutes;<br>(c) a study by the Ministry of Chemical Industry, MCI, of nitrogenous fertilizer production costs; and<br>(d) technical assistance in international procurement. |
| **Implementation:** | 1985-1990 |
| **Project Status:** | With the exception of some delays at NCIC's ammonia plant, all plants under the project have successfully been commissioned. Measures taken to reduce the energy consumption in the large size ammonia plants have exceeded expectations; pollution abatement systems are also operating satisfactorily and all operational training has been completed. Some minor modifications, procurement of spare parts and management training are still due. |

### 2. THE FERTILIZER RATIONALIZATION PROJECT

| | |
|---|---|
| **Beneficiaries:** | Beijing Chemical Experimental Company (BCEC), Beijing<br>Luoyang Chemical Fertilizer Company (LCFC), Henan<br>Yuanping Chemical Fertilizer Company (YCFC), Shanxi<br>Xuanhua Chemical Fertilizer Company (XCFC), Hebei<br>Yunnan Xuanwei Chemical Fertilizer Company (YXCFC), Yunnan<br>The Ministry of Chemical Industry (MCI)<br>The Beijing Institute of Chemical Engineering and Management (BICEM) |
| **Project Cost:** | US$ 184 million equivalent (US$ 110.1 million equivalent in foreign exchange) |
| **Bank Loan:** | US$ 97.4 |
| **Components:** | (a) Establishing a phosphate production capacity (DAP and NPK) at an existing ammonium bicarbonate (ABC) plant in Yunnan; |

(b) converting ammonium bicarbonate fertilizer production in four existing medium size plants to urea, and expanding production capacities with the use of modern energy saving technology; and

(c) carrying out a management efficiency study and a program to introduce modern systems for organization, information and cost management at fertilizer enterprises, and upgrade sector-wide management training capabilities.

**Implementation:** 1987-1992

**Project Status:** All engineering and most of the major procurement contracts have been awarded. Most of the basic has been completed and detailed engineering is in progress. Implementation of the institutional development component is satisfactory.

### 3. *THE PHOSPHATE DEVELOPMENT PROJECT*

**Beneficiaries:** Guizhou Phosphate Company (GPC), Guizhou
The Ministry of Chemical Industry

**Project Cost:** US$ 221.8 million equivalent (US$ 74.1 million equivalent in foreign exchange)

**Bank Loan:** US$ 62.7 million

**Components:** (a) Wengfu Mine Development Component—Establishment of an open-pit phosphate mine at Wengfu, Guizhou Province, with a capacity of 2.5 million tons per year (Mtpy) run-of-mine (ROM) rock and construction of a modern beneficiation plant to produce phosphate concentrate at the mine site and an associated slurry pipeline; and

(b) Technical Assistance Component—consultancy services for project management and mine workshop maintenance, and computer-based sector investment optimization model, developed under the Phosphate Subsector Study by the Bank with data supply by the Chemical Planning Institute (CPI) of MCI, to be installed, maintained and further developed at MCI to strengthen its subsector planning capability.

**Implementation:** 1988-1993

**Status:** Project implementation has just started. Some consultants have been appointed under the Technical Assistance Component and tests required for design have been completed.

### 4. *THE HUBEI PHOSPHATE PROJECT*

**Beneficiaries:** Jinxiang Phosphate Chemical Company (JPCC), Hubei
Huangmailing Phosphate Chemical Company (HPCC), Hubei
The Ministry of Chemical Industry (MCI)

**Project Cost:** US$ 510.6 million equivalent (US$ 162.3 million equivalent in foreign exchange)

**Bank Loan:** US$ 137.0 million

**Components:** (a) Dayukou Mine and Fertilizer Development Component—initiation of a new open-pit mine of 1.5 Mtpy ROM rock capacity, construction of a beneficiation plant, and establishment of a 560,000 tpy TSP fertilizer complex;

(b) Huangmailing Mine and Fertilizer Development Component—capacity expansion of an existing open-pit mine from 0.3 Mtpy ROM rock to 1.0 Mtpy, construction of a beneficiation plant, rehabilitation of a small low-grade nitrogenous fertilizer plant to supply ammonia as feedstock for MAP production, and establishment of a 180,000 tpy MAP plant near the mine site; and

(c) Technical Assistance Component—consulting services for project implementation, technology selection, start-up of operations, mine workshop maintenance, and for training in Hazard and Operability Analysis.

**Implementation:** 1989-1994

**Status:** The project was approved in May 1989. In cooperation with the respective design institutes, CNCCC (China National Chemical Construction Corporation), is preparing short lists and terms of reference for the selection of consultants and technologies.

## IV. FERTILIZER PROJECTS UNDER CONSTRUCTION OR IN PLANNING STAGE

### Nitrogen Subsector

A 1,000 tpd coal based ammonia project including a 900,000 tpy ODDA nitrophosphate plant located in Lucheng, Shanxi province, was commissioned in mid 1988 and is still going through some teething problems, particularly in the nitrophosphate section.

Two locally financed ammonia/urea plants of standard capacities (i.e. 1,000 tpd $NH_3$ and 1,620 tpd urea) and based on international technologies are also in the commissioning phase. They are located, respectively, at Yinchuan, Ningxia autonomic region, and, Puyang, Henan province.

Contracts for three natural gas based large size ammonia/urea plants have been signed: Hejiang, Sichuan province; Fuling, Sichuan province; and Jingxi, Liaoning province. The plants are expected to come on stream in 1992/93.

Additionally, 4 large size ammonia/urea projects are under consideration: Three oil-based plants (Inner Mongolia, Jiangxi and Jilin provinces), and one coal based plant (Shaanxi province).

Two further ammonia plants are included in the Eighth Five Year Plan, which will supply feedstock for downstream DAP plants of a total capacity of 720,000 tpy.

### POTASH SUBSECTOR

The only potash resource of significant capacity in China is the Chaerhan Salt Lake in Qinghai province. After initial trial operations started in the late 1950's, Phase I of the Qinghai Potash Project was initiated in 1985 and is nearing its completion. Phase I has a capacity of 200,000 tpy of KCl and should be in full commercial operation by the end of 1990. Thereafter, a Phase II Project is planned with a capacity of 800,000 tpy and an expected completion date of 1996.

## V. CONCLUSION AND OUTLOOK

According to the projections of the Chinese Ministry for Agriculture, the demand for chemical fertilizers in 1990 will reach about 24 Mtpy of nutrients (i.e. 16.3 Mtpy N, 5.7 Mtpy $P_2O_5$, and 2.0 Mtpy of $K_2O$, nutrient ratio 100:35:12) and will grow to 31 Mtpy of nutrients by the year 2000 (18 Mtpy N, 9.0 Mtpy $P_2O_5$, 4.5 Mtpy $K_2O$, ratio 100:50:25).

As regards nitrogenous fertilizers, the net additional demand for nutrient could be met from:

(i) new capacity,

(ii) improvement in process efficiency in ABC plants and application techniques to reduce volatilization losses, and

(iii) imports.

Because of the high energy consumption and low quality of ABC, the Government has decided not to build any new small size plants and that most of the addition of production capacities would come from large new plants.

With very limited opportunities to increase the arable land area in China, future agricultural growth must almost entirely come from increased intensity of production and higher yields on already cropped lands. This will require, among other things, continued increases in the use of chemical and organic fertilizers of the appropriate type and quality. China's development program addresses these concerns and focuses on three major areas:

(i) increasing the supply of good quality nitrogenous and expanding output of fertilizers with a high nutrient content;

(ii) reducing energy consumption in small and medium size plants and replacing them over time with large efficient plants, where appropriate and feasible; and

(iii) correcting the imbalance in N:P:K ratios. Given the shortage of natural gas, oil and construction funds, the major issues in this strategy are the choice of the appropriate feedstock and the rate of construction of new plants, particularly in view of the large entrenchment in the Government capital construction program.

One of China's main objectives is to become self-sufficient in the supply of all major fertilizer nutrients. However, scarcity of raw materials and the difficulties in exploiting available resources make this objective difficult to achieve, particularly on a short to medium term basis.

Considering the constraints in the supply of oil or natural gas, coal may still be the most appropriate energy source for a number of projects. But unlike mature processes where China can build plants by copying existing designs, the processes for coal gasification are undergoing important changes, and large amounts of financial and human resources are being spent in industrialized countries on process and equipment design, manufacturing and construction methods to improve the efficiency of coal gasification and liquefaction technologies. Consequently, copying existing designs and processes cannot be considered a viable long-term solution since they may quickly be outdated. At the other extreme, China cannot continuously rely on import of whole plants. In the past, this practice has fulfilled an important role in closing a wide gap in China's fertilizer production. But it cannot provide a long-term solution. Accordingly, other alternatives have been sought.

Licensing arrangements, covering process know-how, engineering and manufacturing technology is one such alternative. In many cases, however, foreign suppliers are reluctant to sell licenses to China, since it would deprive them of a lucrative market for their equipment. In these cases one could possibly negotiate the purchase of licenses together with equipment purchase, and give preferential treatment to those qualified process and/or equipment suppliers that are willing to provide China with a continuous flow of know-how.

A more effective and possibly less costly way of acquiring know-how on a continuous basis is to join—possibly initially in combination with a licensing agreement and/or equipment purchases—one or more of the leading groups in the world that are involved in the development of new technologies. Once the process is developed and proved, China could combine its design, engineering, manufacturing, construction and operating capabilities with the capabilities of its foreign partner (primarily process know-how and project management, financial and market strength) to bid jointly with the foreign partner for plants and equipment overseas. In addition to giving China an opportunity for continuous access to the latest developments in the field, this would also provide a source of foreign exchange as well as an impetus for modernizing part of its machine building industry.

The phosphatic and potassic fertilizers are the areas that presently and in the forthcoming future should receive most attention. China is making efforts to develop its sizeable deposits of phosphates in the Southwest and its potash deposits in the West (Qinghai Province). In order to cope with expected growth rates for phosphate fertilizers, medium to large capacities need to be added which should be predominantly producing TSP or MAP to facilitate a reasonably fast increase of the phosphate content in local fertilizers. However, it is expected that some nitrophosphate capacity will also be added, usually producing fertilizers of the 26:13:0 type. China has already indicated that, within its Eighth and Ninth Five Year Plans (1991-2000), it will put particular emphasis on the further development and expansion of its phosphate subsector. In view of the scarcity of elemental sulfur in China and the constraints on the mining and distribution of pyrites, this goal is likely to be achievable only after development of economically viable medium to large scale sulfur recycling technologies.

**TABLE 1**
**CHINA - NITROGENOUS FERTILIZER PLANT CAPACITIES**

**SMALL SIZE PLANTS**

Number: about 1200
Total Capacity: approx. 6-7 Mtpy N
5,000-30,000 tpy $NH_3$
20,000-120,000 tpy ABC

**MEDIUM SIZE PLANTS**

Number: 54
Total Capacity approx. 2.5 Mtpy N
40,000-100,000 tpy $NH_3$
180,000-400,000 tpy ABC

**LARGE SIZE PLANTS**

Number: 19
Total Capacity: approx. 5 Mtpy N
330,000 tpy $NH_3$
570,000 tpy urea (18) or 900,000 tpy NPK (1)

**TABLE 2**
**TYPICAL ENERGY CONSUMPTION IN NITROGENOUS FERTILIZER PLANTS**
**(average during period 1975-1985)**

| | NH3 capacity tpy | Energy Consumption average kcal/t NH3 | Energy Consumption 1985 target kcal/t NH3 |
|---|---|---|---|
| Large plants | >= 300,000 | 10,000 | <10,000 |
| Medium plants | 45-250,000 | 16-18,000 | 14,000 |
| Small plants | < 45,000 | 18-20,000 | 16,000 |

Source: Official sources and missions' estimates.

**TABLE 3**
**PRODUCTION OF PHOSPHATE FERTILIZERS, 1972-86**
**(in thousand tons of $P_2O_5$)**

| | SSP tpy | SSP % | CMP tpy | CMP % | OTHERS tpy | OTHERS % | TOTAL tpy |
|---|---|---|---|---|---|---|---|
| 1972 | 740 | 59.2 | 488 | 39.1 | 21 | 1.7 | 1,249 |
| 1981 | 1780 | 71.0 | 692 | 27.6 | 36 | 1.4 | 2,508 |
| 1983 | 1920 | 72.0 | 715 | 26.8 | 30 | 1.1 | 2,665 |
| 1984 | 1683 | 71.3 | 644 | 27.3 | 32 | 1.4 | 2,359 |
| 1985 | 1345 | 76.5 | 380 | 21.6 | 33 | 1.9 | 1,758 |
| 1986 | | | | | | | 2,340 |
| 1987 | | | | | | | 3,239 |
| 1988 | | | | | | | 3,607 |
| 1989 | | | | | | | 4,000 |

Source: MCI

## TABLE 4
## FERTILIZER APPLICATION RATES FOR VARIOUS COUNTRIES, 1986 <a
(kg per hectare of arable land)

| Country | Nitrogen | Phosphate | Potash | Total | Ratio |
|---|---|---|---|---|---|
| Korea | 195.2 | 89.7 | 100.4 | 385.3 | 100: 46.0: 51.4 |
| Japan | 145.2 | 156.4 | 125.5 | 427.1 | 100:107.7: 86.4 |
| China <b | 137.8 | 31.1 | 7.3 | 176.2 | 100: 22.6: 5.3 |
| France | 135.2 | 75.0 | 98.8 | 309.1 | 100: 55.5: 73.1 |
| Indonesia | 64.0 | 26.2 | 7.7 | 98.0 | 100: 40.9: 12.0 |
| USSR | 49.4 | 36.0 | 28.7 | 114.1 | 100: 72.9: 58.1 |
| USA | 49.4 | 19.2 | 23.2 | 91.8 | 100: 38.9: 47.0 |
| India | 38.7 | 13.2 | 5.1 | 57.1 | 100: 34.1: 13.2 |
| Philippines | 30.9 | 5.8 | 5.8 | 42.5 | 100: 18.8: 18.8 |
| Morocco | 18.1 | 14.0 | 6.0 | 38.2 | 100: 77.4: 33.2 |
| Brazil | 12.8 | 21.9 | 16.7 | 51.4 | 100:171.1:130.5 |

**Source:** FAO Fertilizer Yearbook, 1987, Vol. 37

[a] Rates are based on apparent consumption figures obtained by adding net imports of fertilizers to domestic production.

[b] FAO's apparent consumption figures are not consistent with the consumption actual statistics published by the Ministry of Agriculture due to different statistical methods and bases.

## TABLE 5
## WORLD BANK FERTILIZER PROJECTS IN CHINA
(as of mid 1989)

| Project title | Bank Loan | Tot. Project Cost | Endproduct | Approved in cal. year | Expected completion in cal. year |
|---|---|---|---|---|---|
| | (US $million) | | | | |
| Fertilizer Rehabilitation and Energy Saving Project | 97.0 | 186.6 | Rehabilitation of 5 ammonia/urea plants | 1985 | 1990 |
| Fertilizer Rationalization Project | 97.4 | 184.0 | Rationalization of 5 ammonia/ABC plants: 4 urea plants and 1 DAP/NPK plant | 1987 | 1991/92 |
| Phosphate Development Project | 65.0 | 221.8 | Phosphate rock concentrate | 1988 | 1993 |
| Hubei Phosphate Project | 137.0 | 510.6 | Integrated mine/ fertilizer operation, TSP, MAP | 1989 | 1994 |
| **Total** | **396.4** | **1,103.0** | | | |

## PHOSPHATE SUBSECTOR

### TABLE 6
### CHINA FERTILIZER PROJECTS

| Project | Province | Product | '000 tpy of product ($P_2O_5$) | | Planned year of completion |
|---|---|---|---|---|---|
| Jinchan | Gansu | SSP | 400 | (60) | completed |
| Lucheng | Shanxi | NP (26:13:0) | 900 | (120) | completed |
| Kaifeng | Henan | NP (26:13:0) | 150 | (20) | completed |
| Jinan | Shandong | NP (26:13:0) | 150 | (20) | 1988 |
| Yicheng | Hubei | NPK (15:20:15) | 160 | (30) | 1992 |
| Guixi | Jiangxi | DAP | 240 | (120) | 1990 |
| Tonglin | Anhui | DAP | 160 | (80) | completed |
| Qinhuangdao | Hebei | DAP | 480 | (240)[a] | 1991 |
| Dalian | Liaoning | DAP | 240 | (120)[a] | 1989 |
| Nanjing | Jiangsu | DAP | 240 | (120)[a] | completed |
| Xuanwei | Yunnan | DAP/NPK | 240 | (80) | 1992 |
| Huangnailing | Hubei | MAP | 180 | (93) | 1993 |
| Dayukou | Hubei | TSP | 560 | (200) | 1993 |
| Hangezbou | Yunnan | DAP | 120 | (60) | |
| Zhanjiang | Guangdong | DAP | 60 | (30) | 1991 |
| Huaxian | Shaanxi | DAP | 60 | (30) | |

## TABLE 7
## CHINA
## NITROGEN CONSUMPTION, PRODUCTION AND IMPORTS OF CHEMICAL FERTILIZERS
(in thousand tons of N)

| Year | Consumption | Production | Imports |
|---|---|---|---|
| 1950 | | 15 | |
| 1955 | | 78 | |
| 1960 | | 196 | |
| 1965 | | 1,037 | |
| 1970 | | 1,523 | |
| 1972 | 3,168 | 2,444 | 1,342 |
| 1973 | 3,043 | 2,996 | 1,230 |
| 1974 | 3,490 | 2,827 | 928 |
| 1975 | 4,020 | 3,709 | 964 |
| 1976 | 4,468 | 3,815 | 928 |
| 1977 | 5,065 | 5,509 | 1,147 |
| 1978 | 7,726 | 7,639 | 1,227 |
| 1979 | 8,997 | 8,820 | 1,451 |
| 1980 | 10,180 | 9,993 | 1,537 |
| 1981 | 10,363 | 9,858 | 1,541 |
| 1982 | 10,433 | 10,219 | 1,808 |
| 1983 | 11,923 | 11,094 | 2,365 |
| 1984 | 13,378 | 12,211 | 2,828 |
| 1985 | 13,477 | 11,438 | 2,052 |
| 1986 | 13,728 | 11,592 | 1,700 |
| 1987 | 13,964 | 13,422 | 2,891 |
| 1988 | 15,017 | 13,608 | 4,314 |

Source: Official sources and mission estimates

## TABLE 8
## CHINA
## $P_2O_5$ CONSUMPTION, PRODUCTION AND IMPORTS OF CHEMICAL FERTILIZERS
(in thousand tons of $P_2O_5$)

| Year | Consumption | Production | Imports |
|---|---|---|---|
| 1950 | | - | |
| 1955 | | 1 | |
| 1960 | | 193 | |
| 1965 | | 688 | |
| 1970 | | 907 | |
| 1972 | 1,038 | 1,249 | 11 |
| 1973 | 4,468 | 1,589 | 72 |
| 1974 | 1,390 | 1,390 | 82 |
| 1975 | 1,531 | 1,531 | 34 |
| 1976 | 1,360 | 1,418 | 20 |
| 1977 | 1,415 | 1,708 | 151 |
| 1978 | 1,114 | 1,033 | 246 |
| 1979 | 1,758 | 1,817 | 190 |
| 1980 | 2,368 | 2,307 | 395 |
| 1981 | 2,735 | 2,508 | 499 |
| 1982 | 3,448 | 2,537 | 631 |
| 1983 | 3,945 | 2,666 | 1,028 |
| 1984 | 3,686 | 2,359 | 1,342 |
| 1985 | 3,531 | 1,760 | 950 |
| 1986 | 4,502 | 2,340 | 645 |
| 1987 | 4,763 | 3,239 | 1,159 |
| 1988 | 4,666 | 3,607 | 1,360 |

Source: Official sources and mission estimates

### TABLE 9
### CHINA
### $K_2O$ CONSUMPTION, PRODUCTION AND IMPORTS OF CHEMICAL FERTILIZERS
(in thousand tons of $K_2O$)

| Year | Consumption | Production | Imports |
|---|---|---|---|
| 1950 | | - | |
| 1955 | | - | |
| 1960 | | - | |
| 1965 | | 1 | |
| 1970 | | 5 | |
| 1972 | 12 | 8 | 2 |
| 1973 | 15 | 7 | 15 |
| 1974 | 57 | 5 | 57 |
| 1975 | 40 | 7 | 39 |
| 1976 | 16 | 11 | 6 |
| 1977 | 33 | 21 | 23 |
| 1978 | 45 | 21 | 31 |
| 1979 | 108 | 16 | 108 |
| 1980 | 128 | 20 | 126 |
| 1981 | 251 | 24 | 250 |
| 1982 | 568 | 25 | 489 |
| 1983 | 728 | 29 | 634 |
| 1984 | 804 | 31 | 755 |
| 1985 | 920 | 24 | 364 |
| 1986 | 1,075 | 25 | 600 |
| 1987 | 1,267 | 40 | 1,221 |
| 1988 | 1,734 | 53 | 1,392 |

Source: Official sources and mission estimates

### TABLE 10
### CHINA
### CONSUMPTION, PRODUCTION AND IMPORTS OF CHEMICAL FERTILIZERS
(in thousand tons of nutrients)

| Year | Consumption | Production | Imports |
|---|---|---|---|
| 1952 | 78 | 39 | |
| 1957 | 373 | 151 | |
| 1962 | 630 | 464 | |
| 1965 | 1,920 | 1,726 | |
| 1970 | | 2,435 | |
| 1972 | 4,219 | 3,701 | 1,355 |
| 1973 | 6,654 | 4,952 | 1,317 |
| 1974 | 4,915 | 4,222 | 1,067 |
| 1975 | 5,407 | 5,247 | 1,037 |
| 1976 | 5,844 | 5,244 | 954 |
| 1977 | 6,513 | 7,238 | 1,321 |
| 1978 | 8,885 | 8,693 | 1,504 |
| 1979 | 10,863 | 10,653 | 1,749 |
| 1980 | 12,676 | 12,320 | 2,058 |
| 1981 | 13,349 | 12,390 | 2,290 |
| 1982 | 14,449 | 12,781 | 2,928 |
| 1983 | 16,596 | 13,789 | 4,027 |
| 1984 | 17,868 | 14,601 | 4,925 |
| 1985 | 17,898 | 13,222 | 3,366 |
| 1986 | 19,305 | 13,957 | 2,945 |
| 1987 | 19,994 | 16,701 | 5,271 |
| 1988 | 21,417 | 17,268 | 7,065 |

Source: Official sources and mission estimates

NOTES ON TABLES 7-10:

**Source:** Ministry of Chemical Industry; Ministry of Agriculture, Animal Husbandry and Fishery; General Administration of Customs; State Statistical Bureau; and FAO.

Nutrient composition of compound fertilizers is assumed to be 2:3:1 (N:$P_2$)$_5$:$K_2O$)

Projected imports were derived from supply gaps between domestic production and consumption, taking into account an 8% handling loss.

### TABLE 11
### MAJOR PHOSPHATE DEPOSITS IN CHINA
### (in million tons of rock)

| Province | Deposit | Reserves | Ratio (rock/concentrate) |
|---|---|---|---|
| Hubei | Dayukou | 162 | 2.14 |
| | Wangji | 90 | 2.14 |
| | Fanmasheng | | |
| | Lungwaisheng | | |
| | Yichang | 1,068 | 3.33 |
| | Huangmailing | 110 | 3.33 |
| Guizhou | Kaiyang | 320 | |
| | Wangjayuan | 50 | |
| | Chuanyondong | 280 | |
| | Datang | 160 | |
| | Yuhua | | |
| | Xingiao | | |
| | Xiaoba | 104 | |
| | Yingping | 110 | 1.50 |
| | Wofang | 70 | 1.57 |
| | Dazhai | | |
| Jiangsu | Jingping | 29 | 4.00 |
| Sichuan | Jinhe | | |
| Shaanxi | Han Zhong | | |
| Jiangxi | Cao Yang | | |
| Yunnan | Haikou | 152 | |
| | Kunyang | 105 | |
| | Jinning | 281 | |
| | Anning | | |
| | Chengjaing | | |
| | Longshan | | |
| Hebei | Fanshan | 91 | |
| Hunan | Liyaing | | |

Source: Various international handbooks

### TABLE 12
### AVERAGE ANNUAL PHOSPHATE ROCK PRODUCTION BY PROVINCE
### 1983 - 1985
### (in thousand tons of rock)

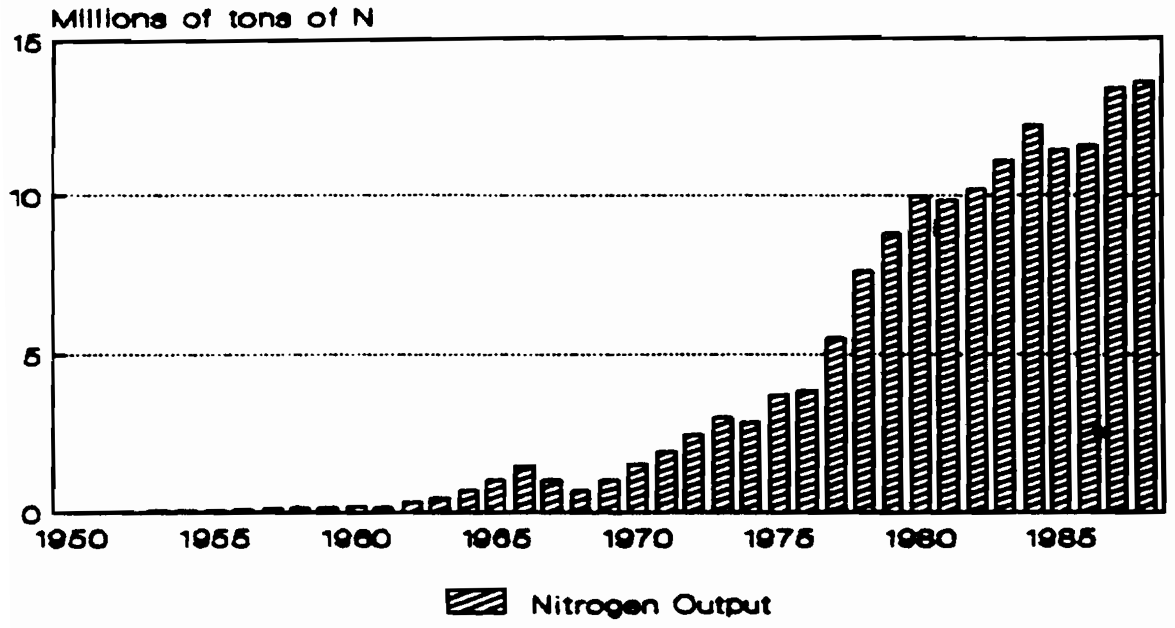
| Yunnan | Guizhou | Hubei | Hunan | Sichuan | Other | Total |
|---|---|---|---|---|---|---|
| 2,952 | 1,829 | 3,372 | 1,048 | 1,314 | 610 | 11,125 |

### TABLE 13
### MAJOR PYRITES DEPOSITS IN CHINA[a]
### (in million tons)

| Province | Deposit | Reserves | Sulfur Content (%) |
|---|---|---|---|
| Guangdong | Yunfu | 206 | 32.1 |
| | Yingde | 37 | 23.2 |
| Neimonggol | Tanyaokou | 72 | 23.3 |
| Jiangsu | Yuntaishan | 9 | 22.8 |
| Hunan | Qibaoshan | 6 | 39.6 |
| Liaoning | Zhangjiagon | 5 | 22.2 |
| Anhui | Xingjiao | 36 | 29.3 |
| | Xiangsham | 129 | 14.8 |
| Sichuan | Chuan Nan | | |
| Zhejiang | Langyou | 5 | 24.0 |
| Shaanxi | Yangguan | 71 | 19.0-24.0 |
| Other provinces | | | |

FIGURE 1

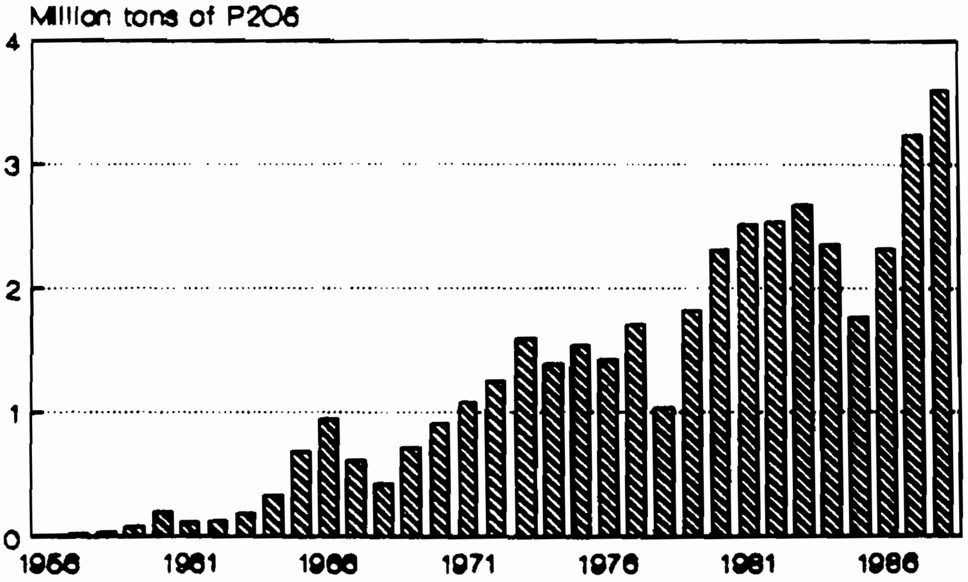
## CHINA
## Nitrogen Production



WBCHINA/KC/9-89

FIGURE 2

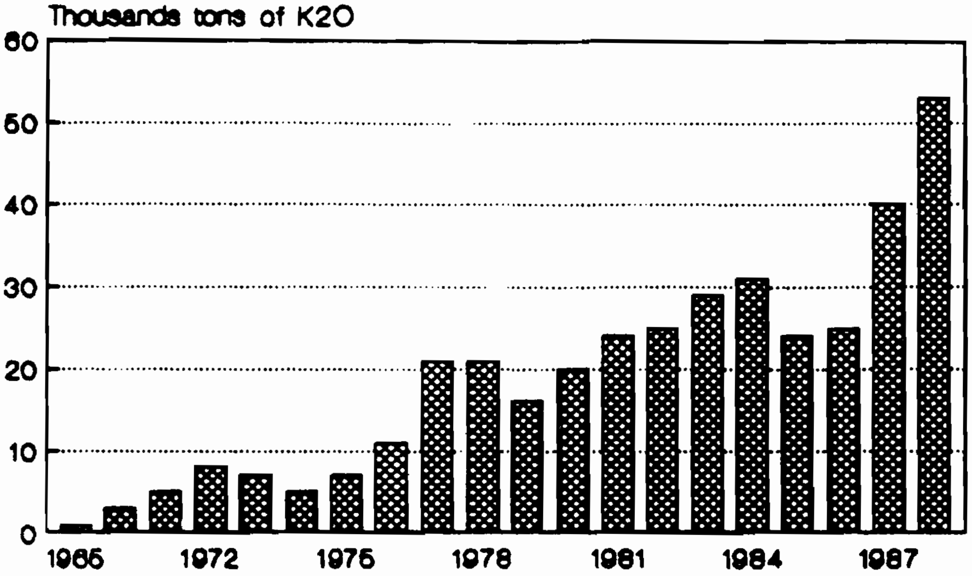
## CHINA
## Phosphate Production



WBCHINA/KC/9-89

FIGURE 3

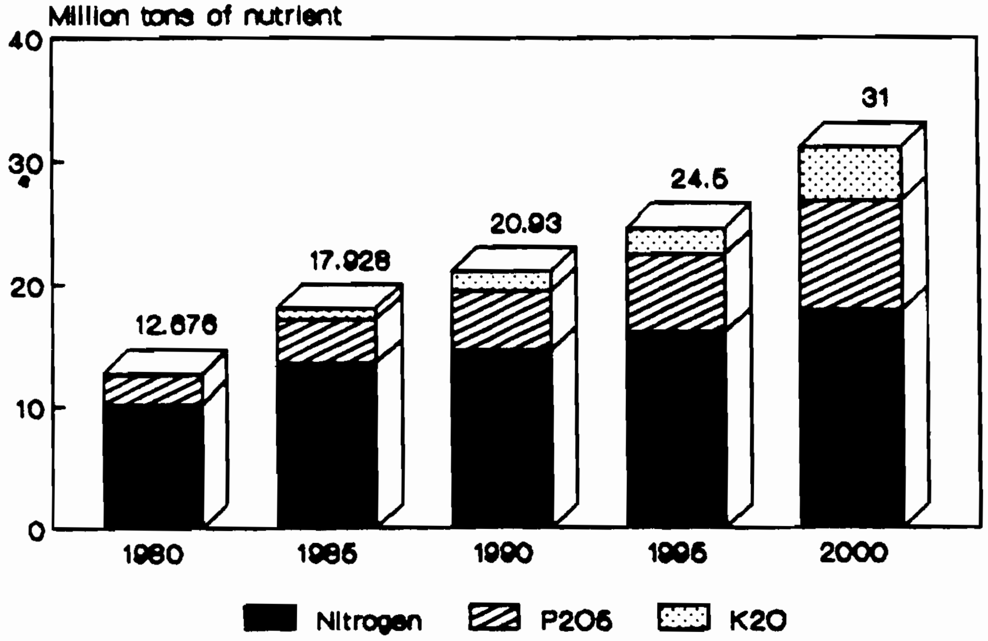
## CHINA
## POTASH PRODUCTION



WBCHINA/KO/9-89

FIGURE 4

## CHINA
## N-P2O5-K2O Application Rates

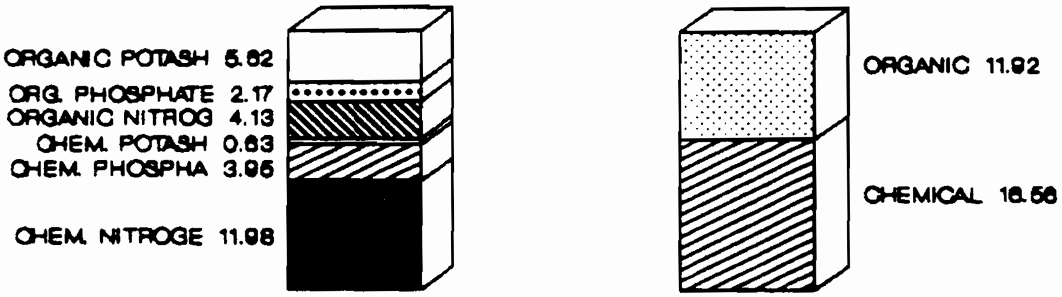


WBCHINA/KO/9-89

FIGURE 5

## CHINA FERTILIZER NUTRIENTS CHEMICAL VS ORGANIC (1985)

(million tons of nutrient)



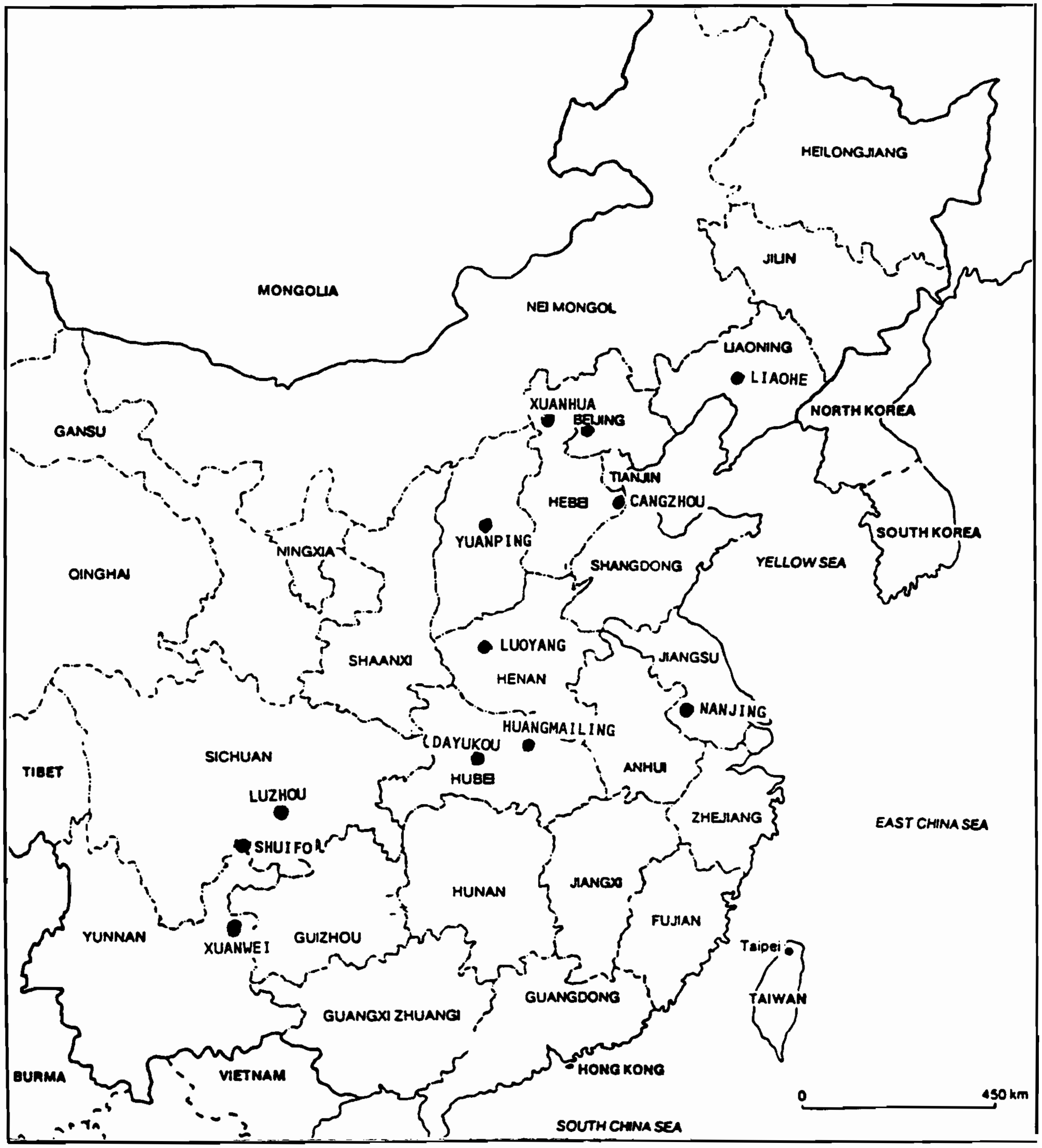
**Total Nutrients: 28.5 million tons**

**N:P2O5:K2O = 100 : 37.9 : 38.8**

WB/KO/9-89

## FIGURE 6

## CHINA
## FERTILIZER PROJECTS FINANCED BY THE WORLD BANK



# Unique Concept for Making Small Ammonia Plants Economically Viable

*T. C. Hicks and A. Pinto*
**ICI Chemicals & Polymers Limited**

## *INTRODUCTION*

The requirement for larger and larger plants very much depends on the rate of growth of demand for the product. Over the past century, the world has seen, with the benefits of modern science, an exponential increase in population which has intensified the need to produce food with greater efficiency. The demand for fixed nitrogen has grown accordingly.

Right up to the late 60's this demand was satisfied by small plants but with the development of the total energy concept ammonia technology the industry was able to meet the increased demand by building large plants.

During the period 1965-85, the traditional size of an ammonia plant has risen steadily from 300 to 1350 metric tonnes per day with indications of continued increases to about 2000 tonnes per day. The large tonnage plant has been the "norm" in the ammonia industry for the last two decades. This pattern is very typical of a rapidly expanding commodity industry but advantages of economics of scale force designers to adopt increasingly more difficult manufacturing and construction techniques.

The demand for large tonnage plants was sustained by a need for self sufficiency in food and it is improable that the past rate of growth can be maintained. The FAO data show a slow down in the world 'N' consumption (Fig 2). With the average growth for the past ten years of 5.7% per annum, expected to drop to 2.8% per annum over the next five years. With this reduction in rate of growth of demand for fixed nitrogen, coupled with monetary constraints and a need to match the infrastructure of the region, a new interest in smaller plants has arisen.

In 1983 market circumstances demanded that ICI's oldest and least efficient ammonia plants at Severnside, near Bristol, England must be replaced. The site had been built around these two plants which produced a total of 900 te/day.

The obvious solution of having a single, large, efficient plant would lose many of the considerable advantages of flexible two plant operation. On the other hand capital and efficiency penalties traditionally associated with small plants seemed to rule out multiple units.

Furthermore, an analysis of ICI's possible replacement and expansion programmes in the future showed that cost effective small plants had many advantages compared to large units.

It was therefore decided to develop new technology to improve the economics of small scale plants.

This was not an easy target. It required a challenging development of new process and engineering concepts and catalysts. Extensive laboratory and on plant pilot scale testing was required. The short timescale required an efficiency and quality in the detailed engineering which was only possible through the use of computer aided design systems by an experienced team.

The result of this effort is the ICI LCA ammonia process.

The paper discusses the process and the methods used in the development of plant design and also the process features which can be utilized for economic expansion and modernization of existing ammonia plants.

The first ICI LCA ammonia plant of 450 MTD ammonia capacity made first product on May 29, 1988. The second plant of the same capacity made ammonia in a world record time of 19 hours from initial introduction of feed gas on 3 October 1988.

The total energy consumption of the new ammonia process is 7.0 million kilocals/tonne. A feature of the process is that it produces more $CO_2$ than required for total conversion of ammonia to urea.

## *TECHNOLOGY DEVELOPMENT*

In January 1984 a study group of experienced ICI engineers and scientists spent a week together to decide whether it was possible to improve ammonia technology sufficiently to enable replacement of the Severnside plants. After the discussion, a flowsheet was drawn up and accepted by the team.

A multi-functional team was appointed to initiate research and development of various alternatives. It rapidly became apparent that effort was required to reduce costs in design, project management and construction.

The team drew up a design during 1984 as a basis for evaluation which showed that the project objectives could be met.

There then followed a long period of testing of alternatives and examination of problems in the laboratory, in the design office and with vendors and fabricators.

An enormous quantity of information was reviewed by the technical management team in a session running for five days in March 1985. This meeting selected the flowsheet which would be used as the basis for design.

The principal test facility for the ICI LCA Ammonia Process has been the Reforming Catalyst Test Unit (RCTU) which was installed in 1985. This pilot scale plant was provided to test the new reforming concept, catalyst systems and metallurgy. The RCTU comprises a single tube version of a Gas Heated Reformer (GHR) complete with a secondary reformer. It operated on steam, air and natural gas as a side steam on one of the Ammonia plants at Billingham and made synthesis gas at a rate equivalent to 5 tonnes/day of ammonia which was returned to the ammonia plant. Control was remote via a computer system which also facilitated data logging and the calculation of performance data.

Aspects of the GHR design which were tested on the RCTU included validation of the process design, long term of the metallurgy and ceramics and the ability of the unit to withstand the normal trip and upset conditions imposed by the operating plant. The control scheme was fully proven as the RCTU was divorced from the main plant and was totally reliant on its own control and trip sequences, being operated remotely from the Research Site about 1 km away.

A pressure swing separation test unit was installed in 1986, and has provided confirmation of the operation and life, as well as high-lighting a number of potential operational problems which were then designed out of the new ammonia plants.

The previous construction of a pressure swing separation plant at Billingham in 1979 meant that ICI had already gained experience of design problems such as hydrogen cracking and noise suppression as well as operational and maintenance problems.

The shift catalyst was tested in pilot scale tubes integrated into the other test units.

The maintenance and operation studies of the plant were carried out using the computer model produced by the piping and layout designers without constructing a plastic model. The design reviews were carried out by a multi-functional team as the detailed piping and layout progressed.

Construction lasted from site preparation in May 1986 to completion in February 1988. Site management was by ICI.

Learning during the construction and commissioning will reduce the timescale on future projects so that LCA complex can be completed and operational in less than two years from release of funds. The critical path will probably lie through design and procurement of the offsite equipment.

## *PROCESS DESCRIPTION*

A flowsheet of the ICI Severnside LCA plant is shown in Figure (3).

Natural gas feed is mixed with recycle hydrogen, heated and desulphurised. It is then cooled by preheating the feed to the desulphuriser before passing to a feed gas saturator where it is contacted with circulating hot process condensate supplying 90% of the pro cess steam. The feed gas from the saturator is mixed with a further quantity of steam to give a steam: carbon ration of about 2.5 and preheated by the reformed gas stream. Reactants enter the primary reformer which operates with an exit temperature of 700-750°C at a pressure of 30-45 bar. The gas mixture is then fed to a secondary reformer for further reforming with an excess of process air. Effluent gas is cooled by providing the heat for the primary reforming reaction and preheating the reactants. The cooled reformed gas is shifted in a single isothermal water cooled low temperature shift converter.

After shift conversion, the gas is cooled by direct contact with circulating process condensate and then fed to a pressure swing separation unit to remove excess nitrogen, $CO_2$ and part of the inerts. A proportion of the available $CO_2$ is recovered from the pressure swing separation waste gas using an aqueous solution of tertiary amine. At Severnside the $CO_2$ is sold by ICI as an industrial gas.

The gas leaving the pressure swing separation unit is methanated, cooled and dried before entering the ammonia synthesis loop at the circulator suction. In the synthesis loop, gas from the circulator is heated and passed over low pressure ammonia synthesis catalyst to produce ammonia.

The hot gas leaving the ammonia converter is cooled by generating 60 bar steam (the first point in the process where steam is raised) and by heating the feed gas to the converter. Ammonia is separated from the partially cooled gas by vaporising product ammonia. The unreacted gas is returned to the circulator.

Argon and methane are removed from the synthesis loop by taking a purge and recylcing back to the synthesis gas generation section as feed.

## *PROCESS FEATURES*

Ammonia production from hydrocarbon feedstocks involves four major processing steps:

1 Feed pretreatment
2 Steam and air reforming of hydrocarbons
3 Gas purification
4 Ammonia synthesis

With conventional ammonia technology, high energy efficiency is only achievable by complex and integrated heat recovery between these processing steps. This energy integration leads to extended plant start-up times and major operational and control problems.

With conventional ammonia technology, high energy efficiency is only achievable by complex and integrated heat recovery between these processing steps. This energy integration leads to extended plant start-up times and major operational and control problems.

The LCA concept on the other hand uses an innovative and imaginative approach to decouple the process steps and eliminate the interactions and interdependencies.

By separating into a 'core' unit only those key operations essential to making ammonia and incorporating steam/power generation, refrigeration and $CO_2$ recovery into a separate 'utilities', the LCA concept offers not only excellent opportunities for efficient site integration of a new plant but also effective expansion and modernization of existing ammonia plants.

This novel concept and design approach provides the following additional benefits:

- Improved efficiency
- Reduced capital costs
- Improved reliability
- Reduced effluents

*EFFICIENCY*

Almost all conventional ammonia plants around the world produce about 5 tonnes of steam per tonne of ammonia from the process waste heat. Steam produced in the ammonia plant is used to meet the process and power requirements of the plant. A typical steam power cycle efficiency is about 25%, and in order to increase this, the steam generation pressure and temperature have to be increased. This increased steam generation pressure, higher than that required for the process, together with the use of back pressure/passout turbine improved the overall steam power cycle efficiency of the plant.

In the LCA process the feed and fuel requirement of the process is 5.8 million kilocals/tonne compared with about 7.0 million kilocals/tonne required for modern low energy ammonia plants. The major reduction in the feed and fuel requirement of the process is achieved by the recycle of process waste heat in the GHR. The fuel saved from the process is available for use in a gas turbine combine power cycle at an efficiency of about 45% to meet the process power requirement.

Other major contributors to efficiency improvements are:

- Low steam ratio operation
- Very much reduced energy requirement for $CO_2$ recovery
- Much reduced inerts levels reducing the synthesis power requirements
- Reduced pressure drop through the synthesis gas generation section of the plant.
- Fast start-up-reduces plant start-up energy requirements

The above efficiency improvements more than outweigh the machine inefficiency due to small plant capacity and increased power requirement of the process air compressor.

*CAPITAL COSTS*

The capital investment for the ICI LCA process is significantly reduced because of the following factors:

- Elimination of the expensive fuel fired primary reformer and its waste heat recovery equipment
- Secondary reformer waste heat recovery system replaced by GHR
- Elimination of two stage shift and expensive temperature control system
- $Co_2$, nitrogen and inerts rejection by pressure swing separation
- Significantly reduced steam generation
- Elimination of purge gas hydrogen recovery unit

*RELIABILITY*

**Only proven unit operations**

All the features which the LCA Process incorporates have been tested either on large pilot plants or on operating plants. The important features are: Gas Heater Reformer, single shift convertor, pressure swing separation, saturation of feed natural gas and the use of an optimised low pressure ammonia synthesis catalyst.

**Maximum knowledge of the plant and its likely operability and performance**

ICI has developed real time models for the new process to simulate any condition that could arise on the plant.

This technique is used:

- to assist in the design of an inherently stable plant which is less sensitive to variation in process parameters
- to study control performance before the plant is built and to make appropriate changes where necessary
- to obtain experience of plant dynamics before commissioning
- to check the effects of equipment failure and the response of the control loops

**Fewer Processing Steps**

The LCA is simple. The size of the reformer is significantly reduced, fuel firing in the reformer and the flue gas waste heat recovery eliminated. Two stage shift is reduced to single stage and the $CO_2$ removal section of the plant is replaced by a pressure swing separation unit. A feed gas saturator simplifies the process heat recovery and removes the need for a high temperature/pressure boiler and a separate process condensate treatment plant.

The effects on plant operation, of disturbances arising from changes in process condition, are reduced.

The process has been designed for inherent stability of operation. As there is no fired reformer the process is much faster to respond to any adjusted conditions.

## EFFLUENTS

The feed gas saturator removes the need to treat process condensate because any ammonia, amines or methanol, which have been formed in the process gas at the secondary reformer and shift conversion stages, are recycled and destroyed in the reformer. The feed gas saturator provides an elegant method of raising 90% of the process steam.

Gaseous effluent from the plant is also minimised because the atomospheric combustion of hydrocarbon fuel is considerably reduced. The noise level is also significantly lower as well as the visual impact on the environment with the reduced size of equipment and plot area.

## INTEGRATED MANUFACTURE OF UREA

LCA is a most effective concept for the integrated manufacture of urea. The process inherently produces more $CO_2$ than required for total conversion of ammonia to urea.

Ammonia processes based on methane have an idealised material balance:

$$7\,CH_4 + 10\,H_2O + 8\,N_2 + 2\,O_2 \rightarrow 7\,CO_2 + 16\,NH_3$$

8 mols of $CO_2$ are required to convert 16 mols of ammonia to urea.

Higher hydrocarbons in the gas help to produce more $CO_2$ but do not solve the problem. The normal design solution is to use a hydrogen rich stream after $CO_2$ removal as fuel for reforming. This is not effective in energy or capital usage.

As the heat of reforming in an LCA process is provided by the combustion of methane to carbon monoxide and steam with excess air there is considerably more $CO_2$ available in the process stream. Only about 90% recovery is required to supply a matching capacity urea plant.

The waste stream from the pressure swing separation system contains about 50% $CO_2$. For $CO_2$ recovery from this stream the partial pressure exit the absorber is about 0.15 bar which would compare with a maximum of 0.07 bar on a conventional process requiring $CO_2$ removal to low levels prior to methanation. A simple and low cost system can therefore be used. ICI has carried out feasibility studies based on a number of $CO_2$ removal systems.

In examining the advantages integration of LCA with urea it is not particularly important which urea process is chosen, as modern processes have very similar energy requirements and nearly 100% material efficiency. There are some differences in the detail of the energy balance but they are minor in effect.

Figure (4) demonstrates a typical integration. This shows one LCA plant and one urea plant. For a urea plant of this capacity an electric motor is sensible for the $CO_2$ compressor in view of its cost and reliability.

The site power and steam demands are supplied by an integrated gas turbine and steam turbine power cycle.

The layout constraints in offsites power generation are more favourable for construction and maintenance than direct drives. ICI has studied the control and operation of this standalone electrical system. Good stability can be achieved with only a small power generation capacity. Motor start places a significant increase in reactive load on the system but this only affects the generator and distribution line sizing.

The independent boiler system allows steam to be raised at start-up for both the ammonia and urea plants. The offsites can be commissioned in advance of the main process plant which minimises maintenance turnaround duration and restart times after a main unit trip.

ICI predicts that the flowsheet energy consumption in practice will be better that 4.95 million kilocals/ tonne of urea or an equivalent of 6.95 million kilocals/ tonne of ammonia, for a natural gas feedstock.

## CONCLUSION

The LCA concept allows a small plant to match the capital and energy efficiency of large plants and therefore opens up exciting new possibilities for the ammonia industry. ICI is now satisfied that small plants are a viable alternative for new plant investment. An LCA plant offers reduced investment risk and short project timescale including rapid commissioning as demonstrated at Severnside. The project is part of ICI's continuing commitment to leading edge technology in ammonia.

The LCA process achieves outstanding environmental standards at no extra cost as part of the design concept. The extra $CO_2$ produced makes the process ideal for the urea producer.

The inherent 12 hour start-up from cold is a design feature as is the consistently achievable low energy requirement.

The elimination of the fired heater reformer improves operability allowing stable operation at as low as 15% of flowsheet.

These features radically improve the ammonia plant characteristics and allow re-optimisation of the economic performance of a fertilizer complex.

The modularisation of many essential parts of the process together with decoupling of processing steps not simplifies on-site construction, but offers exciting options for modernization, expansion and retrofitting existing facilities.

The LCA concept represents the next generation of ammonia technology offering new options for the ammonia/fertilizer industry in meeting the challenges of the future.

## FIGURE 1.
## GROWTH IN WORLD ANNUAL NITROGEN PRODUCTION

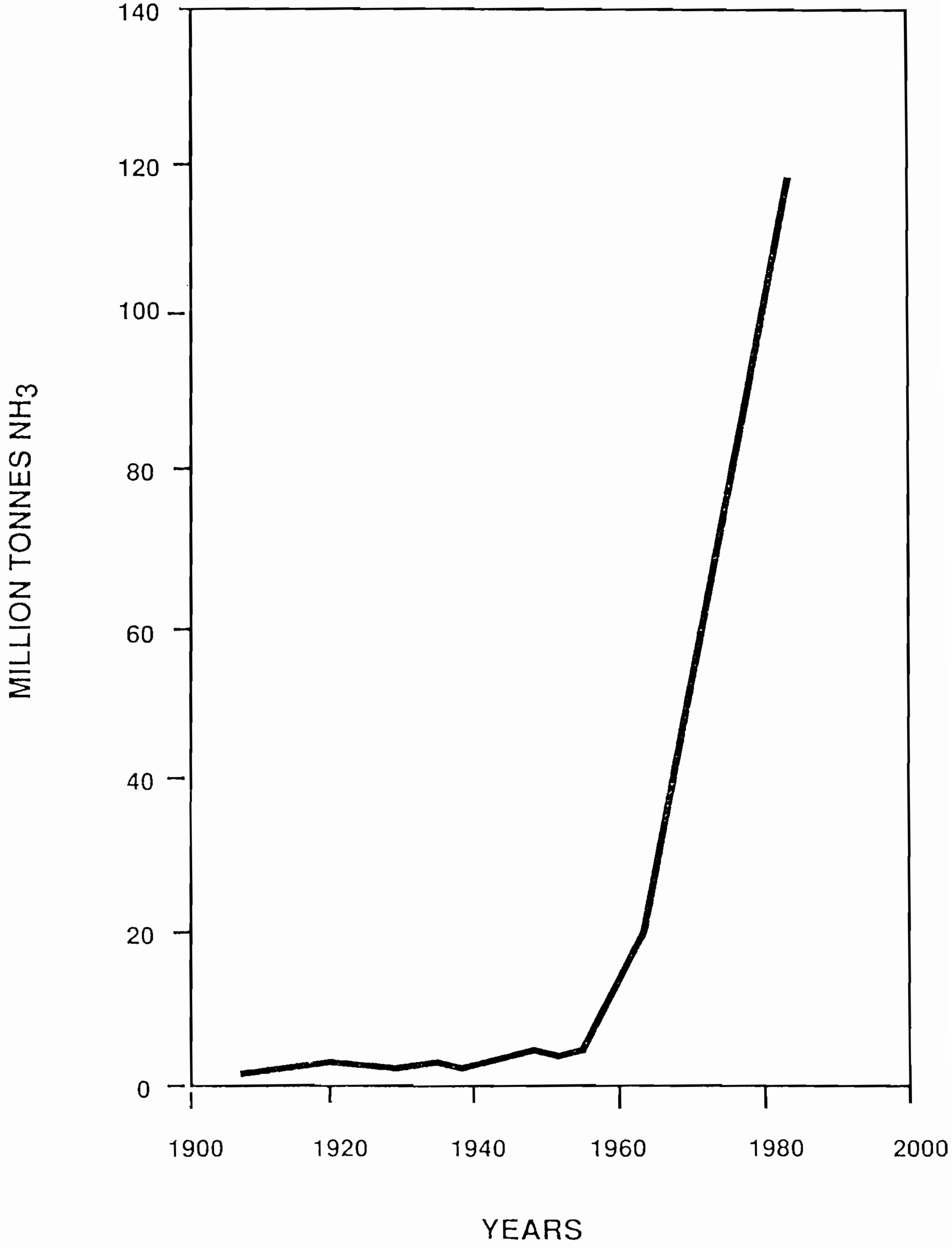
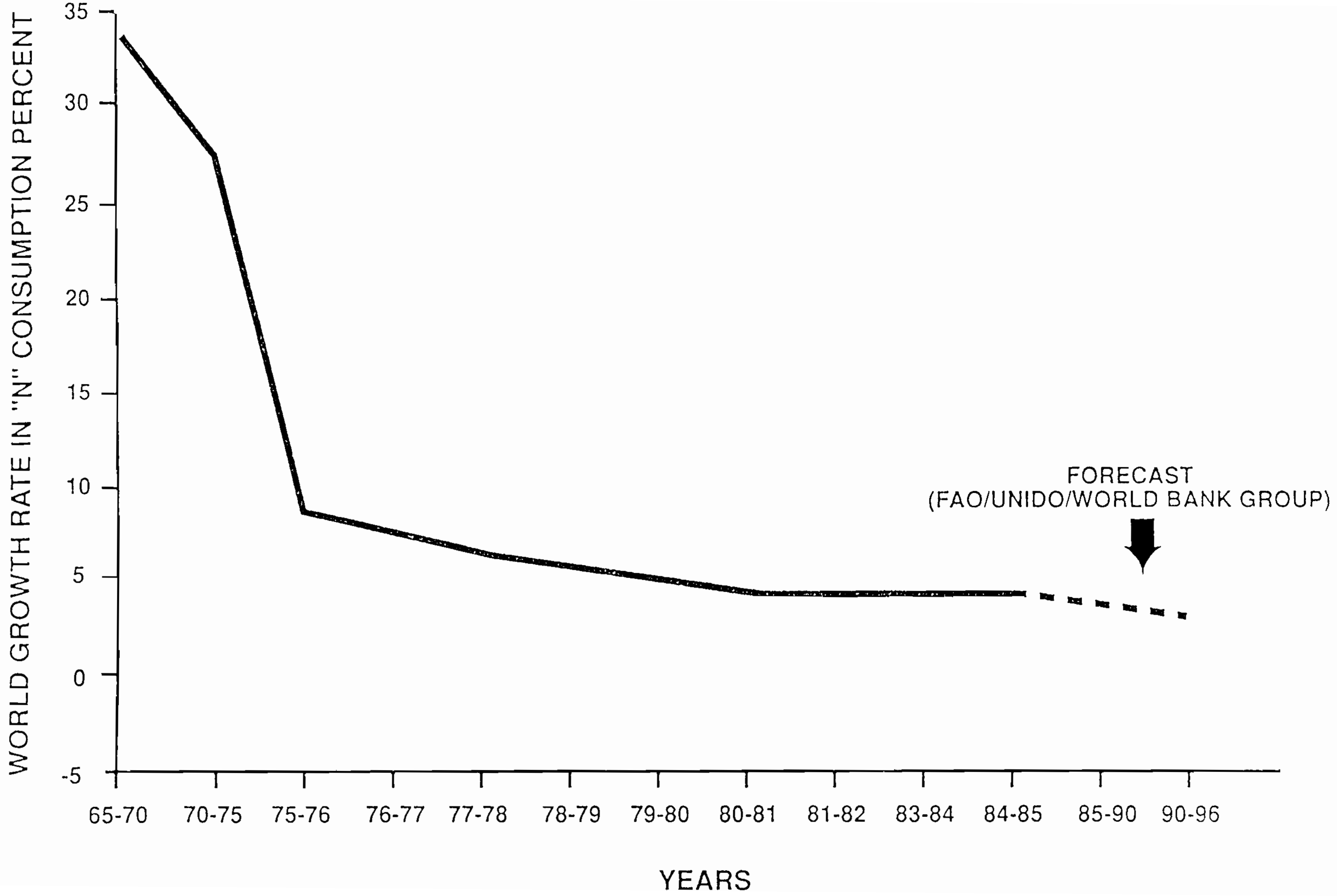
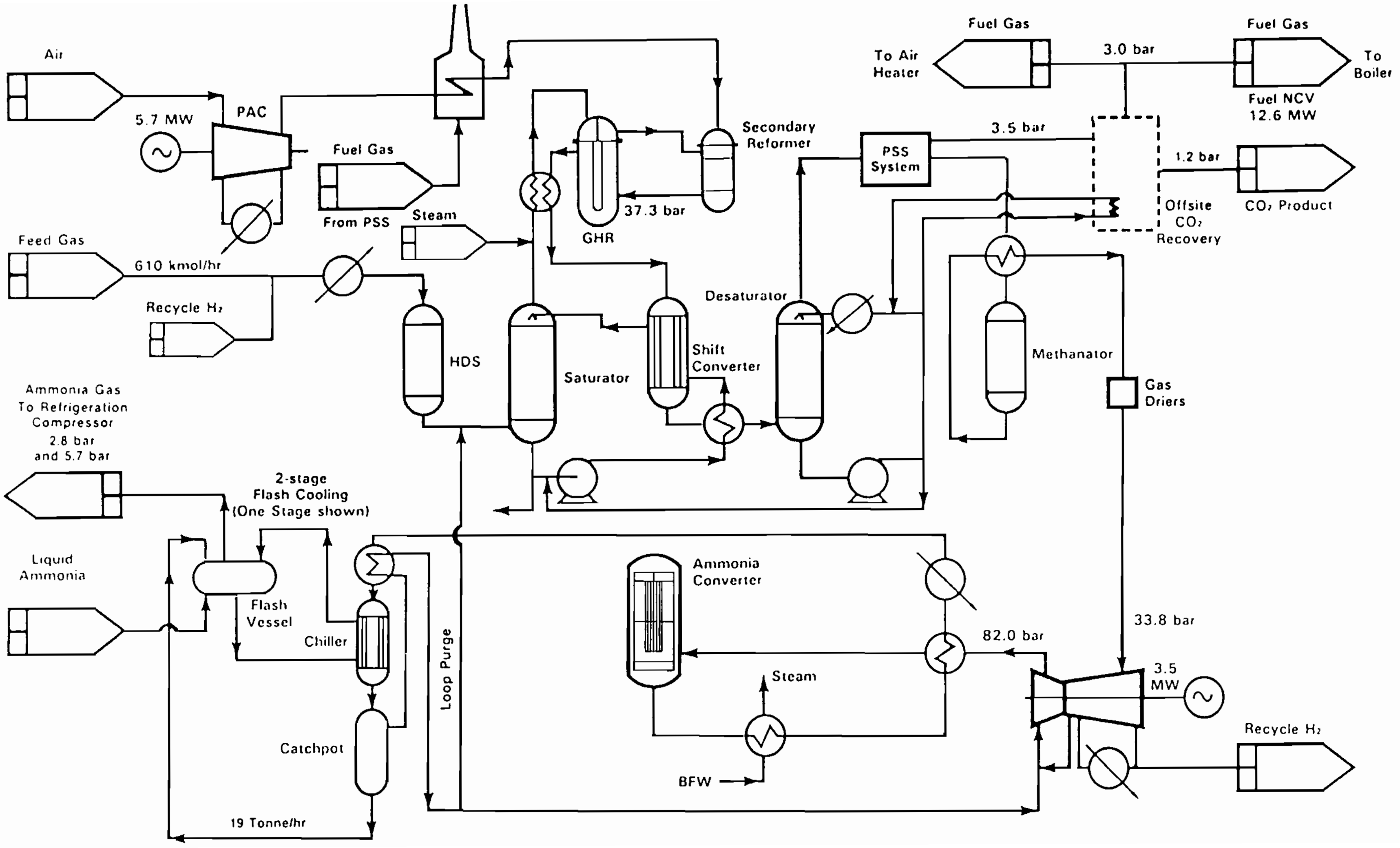


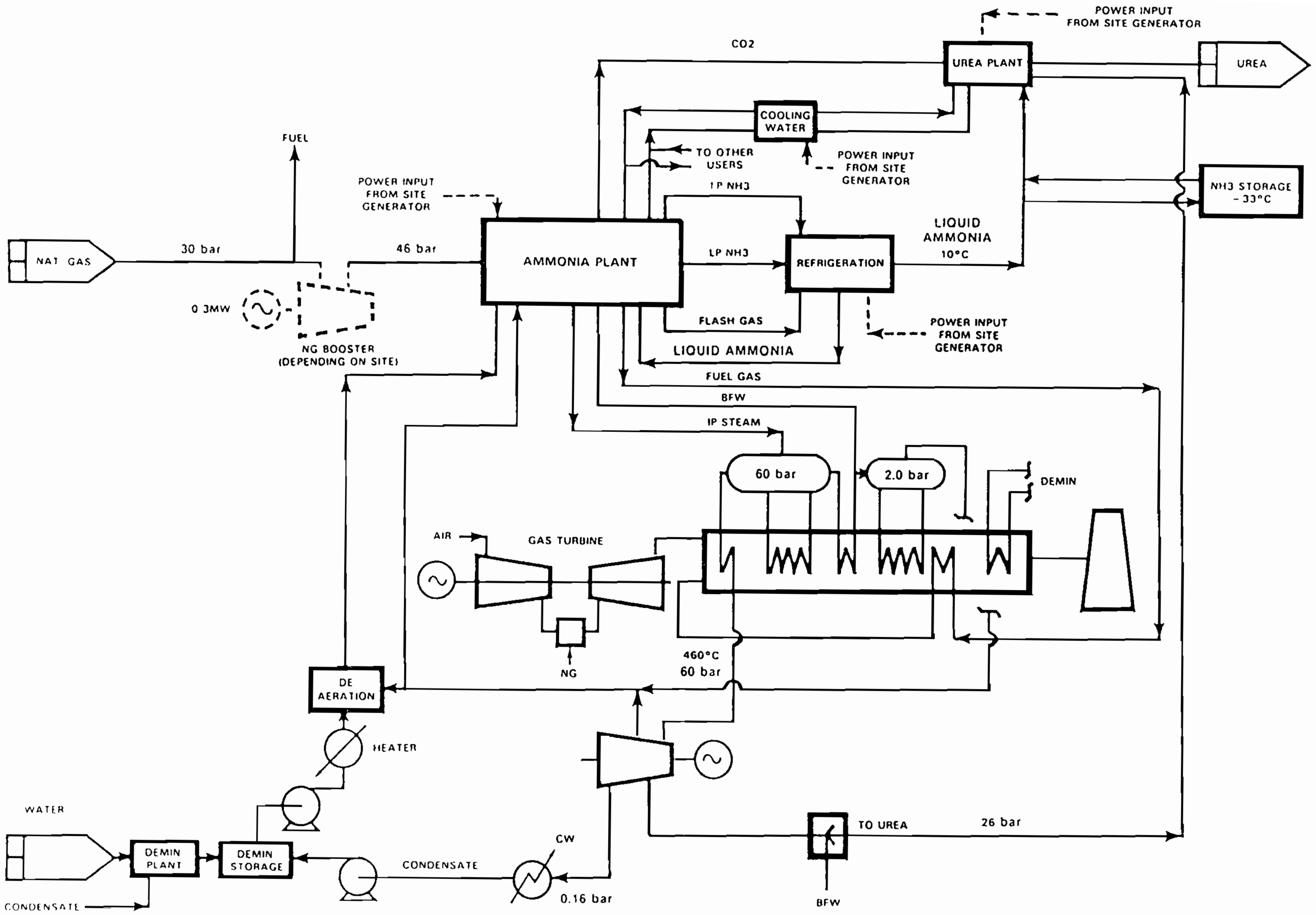
FIGURE 2.
WORLD GROWTH RATE OF FERTILIZER "N" CONSUMPTION



# FIGURE 3.
# LCA PROCESS DIAGRAM



## FIGURE 4.
## LCA/UREA INTERGRATION



# NFDC's Environmental Initiative

*John J. Kohler*
**National Fertilizer Development Center**
**Tennessee Valley Authority**

## *INTRODUCTION*

The publication in 1962 of Rachel Carson's *Silent Spring* (1) is considered by many as the impetus for the development of the American Public's concern for the environment. The environmental movement has grown rapidly in recent years and has become increasingly active in pushing for substantial reduction in the use of pesticides and ensuring the safety and quality of drinking water. Although the fertilizer industry has not been especially singled out by environmental activists, there is an increasing concern for the potential of nitrogen based fertilizer to contribute to the nitrate values in groundwater; and in certain European countries (2), concern over cadmium may soon result in restrictive legislation on the use of certain fertilizer products. The National Fertilizer Development Center (NFDC) has always had a number of environmentally related programs mainly which were related to identifying methods of maximizing the effectiveness of the nutrients applied to the land to reduce both application rates and costs as well as to control dispersal of the nutrients to minimize any potential environmental damage. Over the past several years various fertilizer trade associations and others in the fertilizer industry have seen increased interest in the potential environmental impact of fertilizers and suggested that the NFDC expand its programs in this area. TVA has responded to these suggestions and in 1988 began accelerated development of a comprehensive program to address these concerns. Although the resources devoted to these programs are limited at this time, this enhanced environmental initiative promises to become a major factor in the overall NFDC effort in the near future. This presentation will outline our current program and indicate possible directions for the future. Portions of this presentation have been extracted from papers presented by Frank Johnson (3) and Horace Mann (4) at the 198th National Meeting of the American Chemical Society in Miami Beach, Florida.

## Environmental Initiative

The NFDC's environmental initiative is divided into three functional areas: (1) Containment and compliance; (2) information and education and (3) research and development.

### *CONTAINMENT AND COMPLIANCE*

1. *Model Containment Demonstrations.* About 20 model containment demonstrations are planned for fluid and solid fertilizer facilities across the United States. The purpose of this program is to demonstrate environmentally acceptable "state-of-the-art" procedures for handling fertilizer and fertilizer-pesticide mixtures, minimize undesired discharge of these materials outside plant boundaries, and show other dealers what is required to comply with existing regulations. TVA will share the planning cost with the selected dealers, and dealers will bear all construction costs. Ten sites have already been selected. These sites are in Alabama, Illinois, Maryland, Virginia, Louisiana, South Dakota, Florida, and three in California.

2. *Environmental Site Assessments.* This program is designed to assist dealers in determining the requirements necessary for their facility to meet current and future environmental regulations. This service is available by request and involves a detailed inspection of the site by one of three NFDC staff persons. The dealer will receive both oral and written reports on type of containment systems recommended and a set of generic drawings. NFDC will charge a fee based on a daily rate and expenses for personnel performing such assessments. NFDC is also prepared to furnish site specific drawings at an additional cost.

Additional information on these programs may be obtained by contacting David Salladay, who heads NFDC's Field Engineering section, or NFDC's Business Development staff at Muscle Shoals.

### *INFORMATION AND EDUCATION*

1. *Information System.* The NFDC will establish and maintain a computerized data base of existing and proposed regulations, rules, and guidelines for environmental legislation pertinent to the fertilizer industry. In addition the data base will also list and track nutrient-related environmental research activities and "best management practices" as they are verified. The system will be designed to permit analysis of proposed legislation and identify common approaches to specific environmental problems by tracking state, national, and international trends. This system when operational will provide specific and general information on environmental matters related to the fertilizer industry.

2. *Education.* Information sessions will be held to keep the NFDC staff, fertilizer dealers, and other interested parties abreast of the dictates of environmental laws and to transmit the results of NFDC and other research in lay terms to effectively communicate this information to user organizations.

3. *Collaboration.* TVA will organize and cosponsor regional and national conferences to foster the exchange of information between all parties concerned with environmental aspects of the fertilizer industry. These meetings will be designed to create awareness among representatives of specific public and private sector groups about nutrient-related environmental issues, to bring together groups differing in their

views about solving national problems related to agriculture and the environment, and to direct the flow of *reliable* information about nutrient-related environmental issues to these groups.

Additional information on these programs may be obtained by contacting Frank Johnson or Horace Mann of NFDC's National Program staff.

## *RESEARCH AND DEVELOPMENT*

The Research and Development section of the program includes investigation on nutrient efficiency, chemical and biochemical studies, and chemical engineering reviews of potential processes.

1. *Nutirent Efficiency.* In-house and cooperative research with universities to improve nutrient use by plants will continue and special efforts will be directed to the construction and evaluation of models to determine the interactions that affect efficient plant use of nitrogen. New cooperative projects will include investigations on winter "catch" crops to scavenge nitrate and the development of site-specific soil nitrogen tests for humid regions in the United States. Another part of this program will include relating well-water and groundwater nitrate concentrations throughout the United States to nitrogen source, land use, hydrological properties, and the chemical, biochemical and physiographic characteristics of the soil. Research efforts to develop efficient nitrification inhibitors will continue, and a new effort will be initiated to develop fertilizers compositions with predictable release characteristics. It has been estimated that under the best of conditions, in the year of application, only 50% of the applied nitrogen and 30% of the applied phosphorus are actually used as nutrients by crops and, in actual practice it may be considerably less than that. Thus even modest gains in efficiencies could readily offset the cost of producing such materials.

2. *Chemistry and Biochemistry.* In this program area initial efforts will concentrate on development of methods for the decontamination of soil/pesticide matrices, pesticide removal from dilute waste streams, a survey of pesticide treatment technology, reduction of impurities in fertilizers, and the development of standardized sampling and analysis methodologies.

Many fertilizer dealer sites over the course of time have experienced accidental discharges, leaks, and spills resulting in pesticide contamination of the soil. Decontamination can be a very expensive and frustrating operation. A number of approaches for the removal and/or destruction of the pesticides in such contaminated soils will be investigated which will include aqueous thermal oxidation, flotation/soil washing to remove and concentrate the pesticide, and supercritical fluid extraction. Supercritical fluids are materials which have been raised above their critical temperature and pressure and possess many unique properties which allow separations which are impossible or cost prohibitive with conventional systems. Supercritical fluid extraction is no longer a laboratory curiosity and Kerr-McGee's "ROSE" process (5) which separates various petroleum fractions is now in commercial use at eight refineries in the United States.

Those dealers which prepare fertilizer formulations containing pesticides and/or herbicides generate dilute waste streams (rinsates) which can be difficult to recycle and expensive to dispose of. Various materials are being evaluated as absorbents to remove and concentrate the contaminants for easier destruction or disposal. In addition, such streams may be amendable to biological decomposition and tests will be conducted to identify promising strains of bacteria.

In order not to reinvent the wheel, the NFDC is conducting an extensive survey of available pesticide treatment technology to determine the status of existing technologies for cleanup of soils contaminated with pesticides or excessive nutrients. In addition we will maintain and increase contacts with dealers to identify the types of contamination problems which are most important.

Commercial fertilizers derived from wet-process acid contain a wide spectrum of metallic impurities which were solubilized during the processing of phosphate rock into phosphoric acid. Some of these impurities such as cadmium, lead, mercury, arsenic, beryllium, and vanadium are considered hazardous while others such as iron, aluminum, and magnesium in high concentrations can cause processing problems. It is generally impractical to remove these impurities from the solid fertilizer products so efforts have been concentrated on wet-process acid and liquid fertilizer materials.

There are basically five approaches which can be used for these separations: volatilization, precipitation, extraction, adsorption, and ion exchange. Our initial efforts have concentrated on precipitation and extraction processes. Screening tests have identified sodium trimercaptotriazine, sodium trithiocarbonate, and sodium polysulfide as potential precipitants for cadmium, mercury and lead in 10-34-0 fertilizer solutions. The trithiocarbonate alone shows limited effectiveness with wet-process acid. Extraction studies using liquid aphrons, liquid membrane, and anionic complex approaches have been initiated. The first two approaches employ concepts which generate very large contact areas to facilitate phase transfer but have not proven more effective than conventional extraction in initial tests. The third approach in which cadmium in wet-process acid was converted into a chloro complex and then treated with an amine extractant was very effective and confirmed earlier European work.

Most of the U.S. phosphate rocks, from which most of our acid is derived, are low in most of the hazardous metals. However, some Western rock and some test shipments of foreign rock into the United States in the past several years contain elevated levels of cadmium, and acid derived from such rocks may have objectionable level of cadmium.

One of the most important portions of this program will be the development of sampling protocols and analytical methodologies. Some protocols have already been adopted but others still remain to be evaluated and refined if necessary to ensure that representative samples are obtained. The NFDC will provide the leadership in obtaining acceptance of these protocols.

3. *Chemical Engineering.* Chemical engineering activities include the evaluation and/or testing of materials of construction and containment designs; pilot-plant evaluation of waste-treatment techniques; design, evaluation and testing of alarm and control systems for effluents (rainwater, rinsates, spillage); and evaluation of pumps, valves, and storage/collection systems. Another area which will become of increasing importance in the next several years will be control of emissions from fertilizer facilities as new air-quality regulations come into effect. A program is being developed for this area with emphasis on control of ammonia.

This enhanced environmental initiative is ambitious and has many exciting elements and is heavily oriented to the dealer level. We will require the assistance and cooperation of all segments of the fertilizer industry particularly, in establishing the databases, indentifying best management practices and selecting the most appropriate areas for intensified research activities to bring this initiative to a successful fruition.

In conclusion, I know that with your help our "Spring" will not be silent but filled with singing birds and flowering crops.

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# Wednesday, November 1, 1989

## Session III
## Moderators:

**Whit Yelverton**
**Patrick Peterson**

## Radon From Phosphogypsum Stacks

*Joseph M. Baretincic*
*and*
*William S. Geiger*
**IMC Fertilizer, Inc.**

### *SOURCE OF RADON*

All soil and rock that constitute our planet earth contain uranium and the radioactive elements which derive from uranium. Radon is one of these elements and its abundance is directly proportional to the amount of uranium present unless altered by man. It is somewhat unique in that it is a noble gas, colorless, odorless, and tasteless, but radioactive.

### *WHY THE CONCERN ABOUT RADON?*

The soils of the earth are constantly emitting radon gas. Although its emanation rate may be constant, it has a tendency to build up in dwellings. In most homes, the soil on which it is built contributes 90% of the radon present. Radon enters the home through various cracks and openings that are present in the foundations. The radon gas is unstable with a 3.8 day half life and subsequently decays into radioactive particles of bismuth, lead and polonium. The particles tend to adhere to dust and other tiny particles floating in air which then can adhere to the lung lining where they impact their alpha energy to the lung tissue. The concentration of these radon daughters is measured in "working levels" and cumulative exposures in "working level months". Outdoors, radon usually poses no significant health risk because it mixes with and is widely dispersed in the outside air.

Based upon studies of uranium and other miners, it has been demonstrated that exposure to large concentrations of radon over a prolonged period of time can cause lung cancer. However, we do not know for certain that low doses or dose rates can cause the same effect. For protective reasons, the Environmental Protection Agency (EPA) has taken the posture that low doses also cause human health effects to a directly proportional and lesser degree. For example, note the EPA Radon Risk Evaluation Chart shown in Figure 1, where each 50% decrease in working level (WL) relates to a 50% decrease in the estimated amount of lung cancer deaths at the lower end of each risk level (EPA86)

### *EPA PRELIMINARY STUDY*

The NESHAPS risk assessment methodology requires source term, meteorology, dispersion, and population distribution data (EPA89a). Previous studies had shown that the primary risk from gypsum stacks was from the radon emissions.

The EPA contracted the Pacific Northwest Laboratory (PNL) for a pilot study to construct and demonstrate large area passive radon collection devices and compare them to the PNL flow through system. They were to obtain sufficient radon flux data to develop a statistical sampling plan for estimating the annual average radon flux from a gypsum stack. Their large area radon collector is shown in Figure 2. Measurements were made at one active stack (Gardinier) and one inactive stack (Royster) from April 29 to May 10, 1985. The results of their study and the procedure for making radon flux measurements using large-area activated charcoal canisters (LAACC) are published in the EPA report "Radon flux measurements on Gardinier and Royster phosphogypsum piles near Tampa and Mulberry, Florida" (Ha85)

The EPA then contracted PEI Associates, Inc. to compile additional information on each gypsum stack and perform the required radon flux, environmental radon, and particulate sampling (PEI85). A Peer Review Panel was established to review the sampling plan and data. Members of the panel are shown in Figure 3 (PEI86).

PEI managed the field sampling and quality assurance plan. Environmental samples were collected from July 1985 through July 1986 at 5 gypsum stack locations and several background locations. The gypsum stacks, (Gardinier, Grace, Royster, Conserv, and Estech) were selected because they were representative of the Florida phosphate industry and were studied as part of several other related environmental studies. The Polk County Health Department collected the samples and measured the radon activity of the

LAACC charcoal samples. The other samples were analyzed and the LAACC flux computed at the EPA's Eastern Environmental Radiation Facility (EERF). PEI also compiled site specific information for all of the gypsum stacks in the country. This included the latitude and longitude, operating status, acreage and height, site map, and population distribution within 2 miles of each stack center.

The EPA issued a draft report, "A Study of Radon and Airborne Particulates at Phosphogypsum Stacks in Central Florida", on 12/28/87 (Ho88). This report summarizes the year long study and results, as well as presenting all of the data. Previously, they had issued a draft "Background Information Document—Radionuclide Emissions from Phosphogypsum Stacks—Risk Assessment" on 2/28/87. As expected, most of the calculated risk is from the radon emissions. The radon source term for each stack was determined using factors derived from the study. The overall annual average flux for the active stacks measured in the study was 19 pCi/m$^2$-s. Half of the active and idle stack surface area was assumed to be covered with water resulting in an average flux of 9.5 pCi/m$^2$-s. The inactive stack average flux of 4 pCi/m$^2$-s was used for inactive stacks. An average flux of 2 pCi/m$^2$-s was used for North Carolina stacks based on their relative radium concentration.

The lifetime fatal cancer risk to the maximum exposed individual for his assumed lifetime location and the committed fatal cancers per year within 80 km of each stack were calculated using the EPA models. These values were tabulated for each stack in the country. A comparison of the increased fatal lung cancers due to radon emissions from phosphogypsum stacks and uranium mill tailings was also made. The highest maximum exposed individual risk was 0.08% compared with 2% for the tailings. However, there were 3 committed cancers per year in the regional population (total population living within 80 km of all stacks) compared with 2 for the tailings regional population. Although the individual risks are lower, the larger collective risk are due to the much larger populations within 80 km of the gypsum stacks. Some of the stacks exceeded a maximum individual risk of 1E-4 and the industry regional population risk exceeded 1 death per year, which were decision numbers being considered by the EPA.

## *EPA FINAL STUDY*

TFI coordinated the review of the preliminary analysis and communications with EPA. As a result of these efforts the EPA contracted S. Cohen and Associates to perform additional radon flux measurements on the sides and hard packed roadways on the Grace and Royster stacks. The unpublished report "Supplementary Radon-222 Flux Measurements on Florida Phosphogypsum Stacks June 4-11, 1988" is included in the NESHAPS public docket (B188). Corrections to errors in the stack and nearest residence descriptions and technical comments were also submitted to the EPA.

The "Draft Environmental Impact Statement for Proposed NESHAPS for Radionuclides—Background Information Document" (DEIS) uses these supplementary measurements, additional information on Western stacks, and IMC Fertilizer data on beach flux values and stack configurations to more realistically estimate the radon source term for the gypsum stacks (EPA89a). The values used are summarized in Figure 4.

In the EPA model, the calculated risk for a gypsum stack is directly proportional to the radon source term. Thus this more realistic model of the stack source terms significantly reduces the calculated risk. For example, the source term for the IMC stack in the preliminary study of 540 Ci/y was reduced to 290 Ci/y in the DEIS. The average flux was reduced from 9.5 to 5.7 pCi/m$^2$-s. Corrections to the location of the "maximum exposed individual" further reduced the "maximum lifetime fatal cancer risk to an individual" for some of the stacks.

Although the DEIS still has 5 stacks with maximum lifetime risk to an individual of 1E-4 or 2E-4, it recognizes that 2 are over estimated and TFI has submitted corrections which show that all are less than 1E-4. The risk to the total regional population living within 80 km of a stack was reduced from 3 to 0.97 committed fatal cancers per year. This brings the risks from the gypsum stacks within 3 of the 4 NESHAPS safe or acceptable risk policy approaches. TFI has submitted comments to the EPA showing that even these low calculated risk are over estimated (TFI89).

## *EPA PROPOSED STANDARDS*

On March 7, 1989 the EPA proposed National Emission Standards Hazardous Air Pollutants; Regulation of Radionuclides (EPA89b). Section VII H of the proposed rules addresses Phosphogypsum stocks and suggested the following four approaches for comment.

*Four Policy Approaches for*
*Control of Phosphogypsum*

Approach A:
Case-by-Case Approach.
Acceptable Risk: $2.0 \times 10^{-4}$ (20 pCi/m$^2$-s)

Approach B:
Incidence Based Approach.
Acceptable Risk: One fatal cancer per year
(6 pCi/m$^2$-s)

Approach C:
$1 \times 10^{-4}$ or Less Maximum Individual Risk Approach.
Acceptable Risk: Radon Emission limit of
(2 pCi/m$^2$-s)

Approach D:

$1 \times 10^{-6}$ or Less Maximum Individual Risk Approach.

Acceptable Risk: Radon Emission Limit of (0.02 pCi/$m^2$-s)

The EPA contractor then took the four policy approaches and developed an industry cost per approach vs incidence analysis as follows (Be88).

**INDUSTRY COST PER APPROACH VS. INCIDENCE**

| Approach | Incidence | Total Incident Reduction | Cover (meters) | Total Annualized Cost (millions) |
|---|---|---|---|---|
| A | 0.97 | - | 0 | 0 |
| B | 0.83 | 0.14 | 0.5 | 43 |
| C | 0.29 | 0.68 | 1.0 | 68 |
| D | <1 * | .8 * | 4.0 | 300 |

*Scaled values EPA states cannot be accurately estimated

*DISCUSSION OF THE FOUR APPROACHES*

Approach A, with modification, the phosphate industry feels is the most acceptable proposal since it (20 pCi/$m^2$-s) had already been accepted by the EPA as a standard for Uranium Mill Tailings. This risk/incidence level of 0.97 predicted (by modeling) deaths/yr. within 80 km is just below the EPA incidence-based approach alternative acceptable level of less than 1 death per year. This approach for all practical purposes allows for closed phosphogypsum stacks to remain uncovered forever.

Approach B is a borderline situation in that a number of operating stacks presently could meet the 6 pCi/$m^2$-s radon exhalation maximum with maintaining 50% or greater water coverage. However, leachate collection and treatment on an inactive stack could result in higher long-term costs than capping and preventing the continued infusion of rainwater. The 43 million dollar cost for the 0.5 meter cover is probably too low since the earth hauling costs are based on a ten mile round-trip availability of material.

Approach C presents a more formidable problem to the industry, especially in Central Florida. Where will all this earthen cover come from? A 2 pCi/$m^2$-s exhalation rate is 10 times less than what was deemed acceptable for Uranium Mill Tailings and is less than 10 times greater than typical background soil.

Approach D is the proposal certain environmental groups, especially Manasota$^{-88}$ have latched onto since the EDB case ruling where a risk of $1 \times 10^{-6}$ or less is considered to be acceptable. In this instance an exhalation rate of 0.2 pCi/$m^2$-s would be required which, of course, is near or below background levels. The cost for compliance is roughly estimated at 300 million dollars.

*HOW DANGEROUS IS EXPOSURE TO LOW LEVEL RADIATION?*

The EPA has recommended an action level of 0.02 WL or 4 pCi/1 of radon in homes to protect human health (EPA86). This exposure rate corresponds to a life time lung cancer risk of 13 to 50 out of 1000. The NESHAPS maximum individual risk approach is a lifetime risk of 1E-4 or 1 chance in 10,000. In 1983 there were 113,038 deaths, including 7,877 lung cancer deaths in Florida. This is a typical lifetime lung cancer risk of 70 out of a 1000 or 697 out of 10,000. Furthermore, more than 80% of the regional population within 80 km of a gypsum stack have an EPA calculated increased risk of less than 1 chance in a million.

The radon concentration contribution from a gypsum stack falls off rapidly with distance from the stack. The radon contribution in each direction and the average contribution vs. distance for the IMC stack, which is one of the larger stacks, is shown in figure 5. The typical outdoor radon concentration is also shown and shows that the gypsum stack is insignificant at distances greater than a kilometer or two from the center of the stack. The EPA calculated radon contributions, scaled to the natural background radon flux for the area covered by the gypsum stack is also plotted for comparison. It also shows that at distances greater than a kilometer, there are natural background areas the same size as the stack and between the stack and the reference location, that contribute an equal or greater risk.

The regional population risk out to 80 kilometers from each stack was estimated by dividing the area into sectors for each compass point and varying distance groups from the stack. Figure 6 shows the average concentration and the radial distance groups used for the IMC stack. The average concentration and population in each sector were used to calculate the sector population risk and all of the sector risks added to obtain the regional risk for the stack. Figure 7 shows the average sector concentration and total sector population for radial distance groups for the IMC stack. Note that the radon concentration contribution for most of the regional population is less than 1/1000th of the typical background outdoor radon concentration.

The previous comparisons were based on EPA calculations. TFI submitted a 163 page comment document, with even longer appendixes, to the EPA showing numerous areas where the EPA methodology overestimated the risk from gypsum stacks and giving legal arguments against the extreme alternative proposed approaches (TFI89).

A second undesirable effect of treating conservative, upper bound results as reality is their use in cost-benefit ratios. Since costs are generally underestimated, the ratio is doubly distorted giving a value which is much too low. This may cause incorrect decisions to be made which waste money or preclude economic alternatives which may have served society better.

Screening itself is a valuable tool. Demonstration that grossly conservative dose/risk estimates, perhaps based on simplified models using a minimum of site-specific data, conform to regulations may obviate the need for a more expensive and time-consuming detailed assessment. But the distinction between screening and assessment must be kept in mind. For a state-of-the-art risk assessment, upper-bound estimates masquerading as the most accurate achievable estimates, will not serve.

## *CONCLUSION:*

It is usually the posture of the EPA to favor the first suggested proposal (in this case Approach A). There is some advantage to both parties in Approach A since it offers flexibility on control (case-by-case). It would be our guess that since Approach A has resulted in many negative comments from the militant environmental groups, the final rule expected October 31, 1989 will be a modified Approach A.

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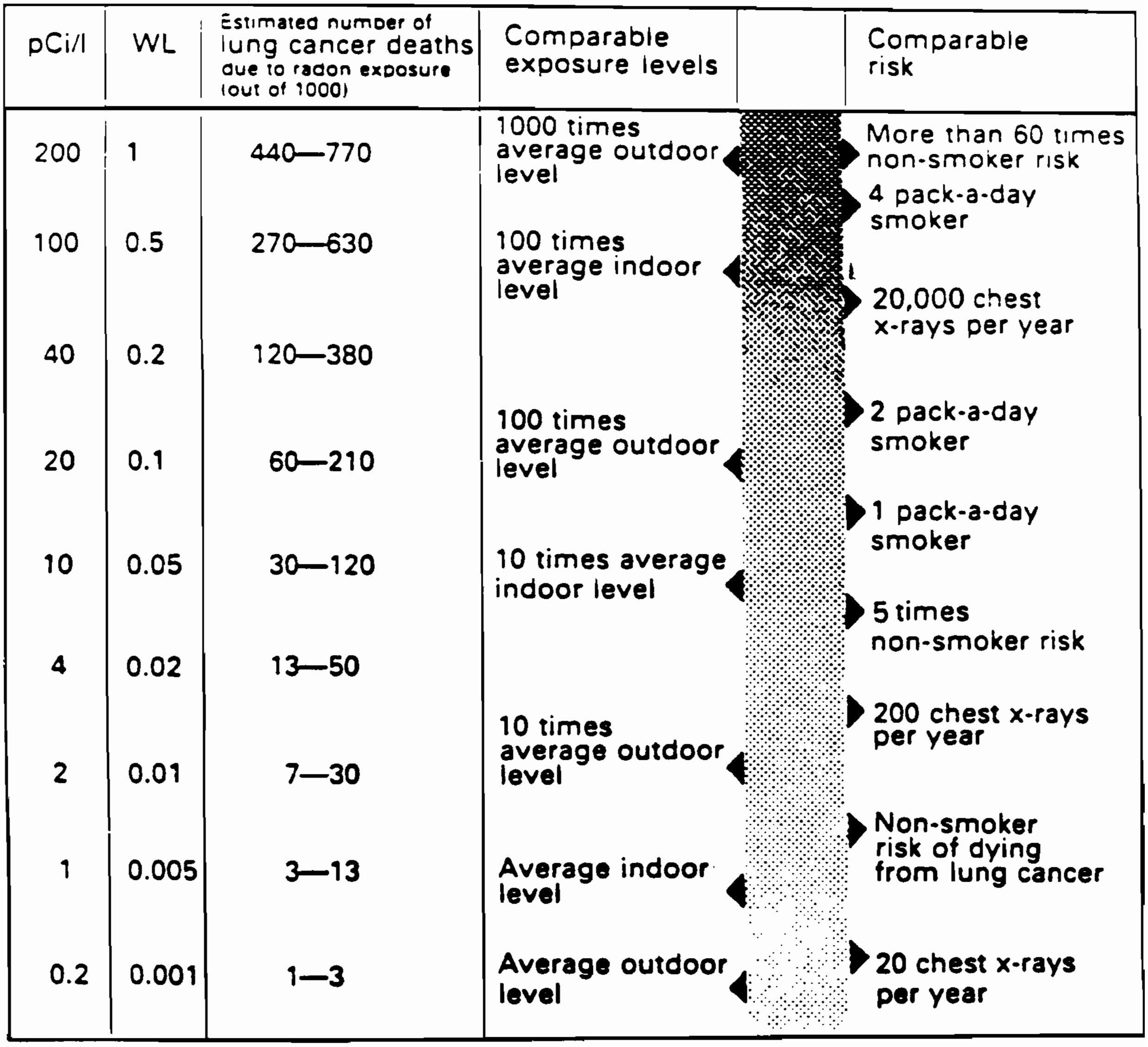
## FIGURE 1

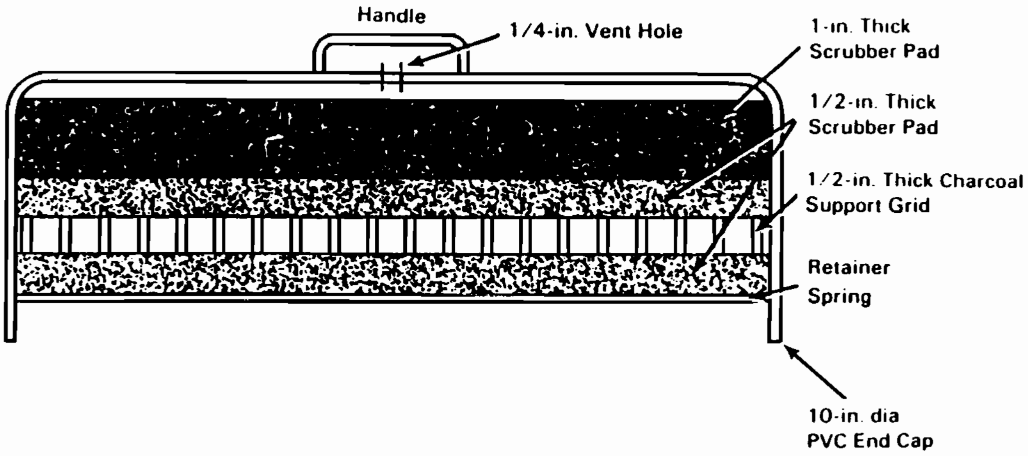
## Radon Risk Evaluation Chart



| pCi/l | WL | Estimated number of lung cancer deaths due to radon exposure (out of 1000) | Comparable exposure levels | | Comparable risk |
|---|---|---|---|---|---|
| 200 | 1 | 440—770 | 1000 times average outdoor level | | More than 60 times non-smoker risk<br>4 pack-a-day smoker |
| 100 | 0.5 | 270—630 | 100 times average indoor level | | 20,000 chest x-rays per year |
| 40 | 0.2 | 120—380 | | | |
| 20 | 0.1 | 60—210 | 100 times average outdoor level | | 2 pack-a-day smoker |
| 10 | 0.05 | 30—120 | 10 times average indoor level | | 1 pack-a-day smoker |
| 4 | 0.02 | 13—50 | | | 5 times non-smoker risk |
| 2 | 0.01 | 7—30 | 10 times average outdoor level | | 200 chest x-rays per year |
| 1 | 0.005 | 3—13 | Average indoor level | | Non-smoker risk of dying from lung cancer |
| 0.2 | 0.001 | 1—3 | Average outdoor level | | 20 chest x-rays per year |

## FIGURE 2

## Large-Area Radon Collector



## FIGURE 3

### Peer Review Panel

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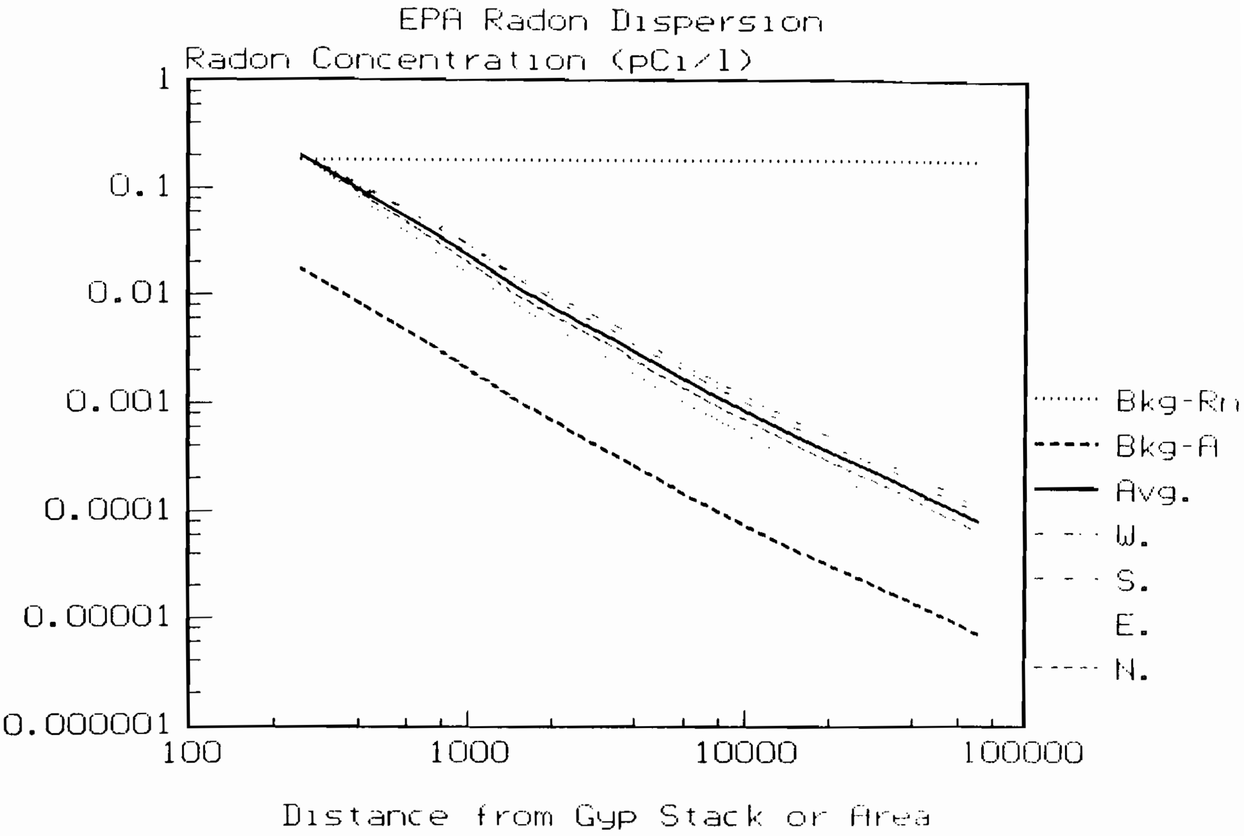
## FIGURE 4

| Region of Stack | Flux (percent of Top Area) pCi/m$^2$/s Florida[a] | North Carolina | Idaho[b] |
|---|---|---|---|
| | **ACTIVE STACKS** | | |
| **Top** | | | |
| Pond/Ditches | 0.0 (60%) | 0.0 (60%) | 0.0 (25%) |
| Beaches | 0.5 (15%) | 0.5 (15%) | 0.5 (5%) |
| Dry Material | 20 (20%) | 4 (20%) | 4.5 (65%) |
| Roads | 13 (5%) | 4 (5%) | 10 (5%) |
| **Sides** | 9 | 4 | 14 |
| | **INACTIVE STACKS** | | |
| **Top** | 4 | (c) | 7 and 1 (d) |
| **Sides** | 15 | (c) | 9.5 and 3(d) |
| | **IDLE STACKS** | | |
| **Top** | 4 | 1 | 7 |
| **Sides** | 12 | 2 | 9.5 |

**(a)** Values applied to stacks in all states except North Carolina, Idaho, Utah, and Wyoming.
**(b)** Values also applied to stacks located in Utah and Wyoming.
**(c)** Inactive stacks do not exist in North Carolina.
**(d)** Applies only to Chevron Chemical Co. stack at Magna, Utah.

## FIGURE 5



## FIGURE 6

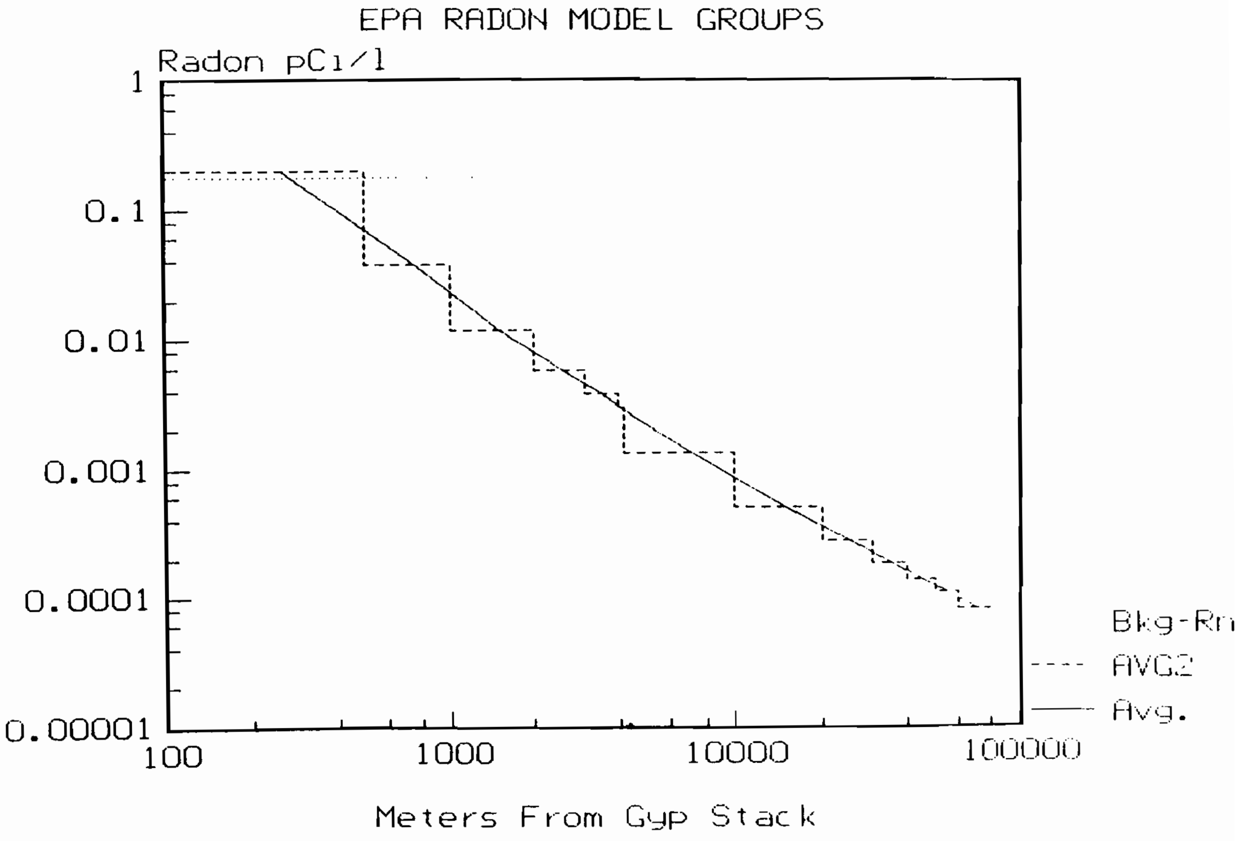
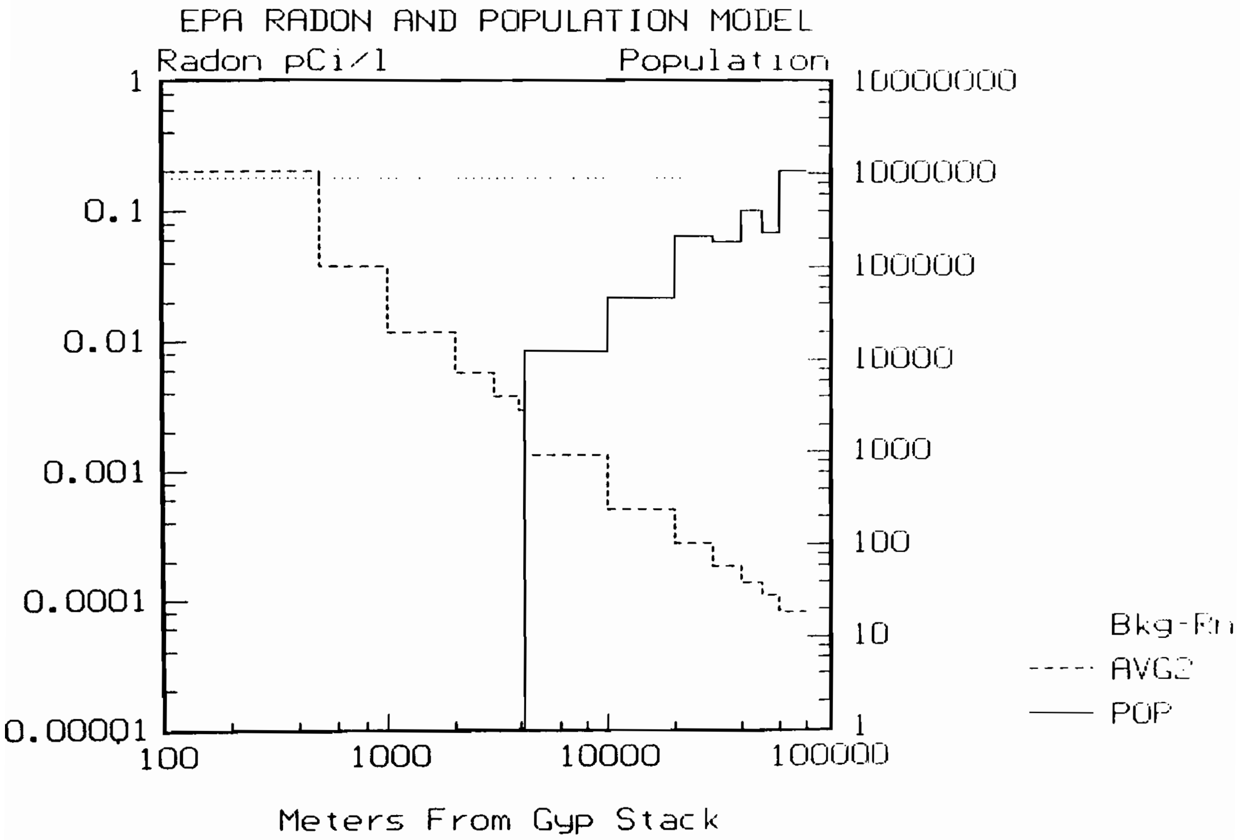


**FIGURE 7**


EPA RADON AND POPULATION MODEL
Radon pCi/l
Population
1
0.1
0.01
0.001
0.0001
0.00001
10000000
1000000
100000
10000
1000
100
10
1
100
1000
10000
100000
Meters From Gyp Stack
Bkg-Rn
AVG2
POP

# The Role of the Lobbyist for the Fertilizer Industries

*Remarks of*
*Rosemary O'Brien*
**CF Industries, Inc.**

## *BACKGROUND*

CF Industries, Inc. opened its federal government affairs office in Washington, D.C. in 1978. Like many other companies which came to Washington in the late 1970s, CF Industries understood that federal action would have an increasing impact on business. At this time, our office consists of two professionals who are registered lobbyists and one support staff.

Our responsibilities are primarily to handle legislative and regulatory affairs for the company. While we monitor a host of activities, most of our time is spent on the few major issues with the greatest potential impact on the company's profitability. Over the last eleven years, these "bottom line" issues have included tax and international trade problems, transportation policy and important environmental concerns.

## *WHAT DOES IT TAKE TO BE AN EFFECTIVE FEDERAL LOBBYIST?*

The task of lobbying the federal government has become increasingly complex in the 1980s. I don't see it getting any easier in the 1990s. Given the expansion of federal government concerns as well as the number of organizations with Washington lobbyists, the ability to communicate quickly and precisely has become essential to success. Only by such communication can a lobbyist overcome what is now characterized as the problem of "special interest gridlock." There are over 15,000 registered lobbyists in Washington today, tracking thousands of bills introduced in Congress and regulations under Administration consideration.

In the past, many public affairs people in Washington came into their jobs with little government experience. Today, lobbyists are often experts on the issues they deal with, and, just as often, have the benefit of previous government experience.

Today's lobbyist must be a mixture of generalist and specialist. For example, I am not a scientist, so I must depend on technical experts from CF's operating divisions to explain complex environmental technologies to congressmen. I do need a general working knowledge of these technical problems in order to negotiate with other political players when a bill is under consideration. In order to accomplish the company's political goals, however, requires a specialist's knowledge of government and the agendas of individual politicians and committees.

The lobbyist must also be a good communicator, and the tools available to help this requirement are impressive. The revolution in computer technology allows instantaneous communication with the Hill staff and the Administration. Mass communication managed by computers has created an unprecedented power in the "grassroots" political sector. Many companies and organizations are only now beginning to exploit grassroots power.

We also use this technology and approach in fashioning a strong internal company communications program. Our Washington office is in daily contact with all key management personnel at headquarters and our operating locations. Our political action committee publishes its own newsletter, and we also publish a monthly newsletter for employees about issues of importance to the company. In addition, if an issue is critical, we create a special report for all employees.

The most important quality a lobbyist needs is credibility. It is true that lobbyists must be advocates and educators, but they can be neither without credibility. As the saying might go, "you are only as good as your last presentation." One certain requirement for the lobbyist is that he or she knows the art of compromise, the heart of congressional politics.

## *ISSUES MANAGEMENT*

Congressmen always seem pressed for time and often will not be focused on the issues important to your company. Further, not all Congressmen are created equal with respect to sophistication or effectiveness. Generally, several terms must pass before a Congressman can begin to grasp the "big picture" of legislation. However, in almost every case, congressmen look at an issue from two sides: first, is this favorable to my constituents? and second, is it good public policy?

The lobbyist addresses these questions by deciding the best way to communicate the company's message in a way that answers them in the affirmative. This may require packaging the tools of grassroots support, executive visits with politicians, advertising and public relations efforts. Trade associations and consulting lobbyists with special area expertise may also enter the equation.

On issues where your industry is split internally and the trade associations are rendered incapable of action due to disagreement, it may be necessary to form broad-based coalitions of different industries. Often these coalitions are made up of strange bedfellows. It is from this need that the saying "no permanent friends, no permanent enemies" gains currency in Washington.

Timing is often the critical element of a successful lobbying program. As the communications revolution has increased the amount of information available, the ability of politicians across the board to concentrate on any one issue has been generally reduced. No matter how much information is available, it is probably true that Congress will never get much faster in doing its work. This means that, for lobbyists, patience may be the cardinal virtue. Members of committees with oversight of specific issues may have the time and expertise to really dig into an issue; but in the final analysis the whole Congress must vote. So the message must be packaged to appeal to both the expert and the layman.

A few general rules are helpful to mention.

- Be brief and scrupulously honest in your presentations; if you are perceived to understand the subject, your opinion on it will be sought again.
- Understand in as much detail as possible the positions of your opponents.
- Hold the member of Congress or the Administration accountable for acting; let them know that their decision will be communicated to a lot of people.
- Finally, it is important to thank the congressmen or other politicians for making the effort to hear your case and possibly assist you.

### *THE ENVIRONMENTAL MOVEMENT*

The environmental lobby is an amorphous group of organizations which generally concentrate on the broad range of big issues such as deforestation, ocean pollution, air pollution, etc., and the more finite concerns of communities. Environmental lobbyists, some of whom were once viewed as extremists, are today very well organized and very effective. They are usually well-educated and very effective communicators.

The environmental lobby can be expected to press its agenda harder during the Bush administration than it did under Reagan. Congressmen from individual states also report that their constituents—the voters—are demonstrably more "pro-environment" than is the business community. The challenge now facing business is to regain environmental credibility. Business must communicate its own concern for the environment and publicize its positive actions. At the same time, business must work for environmental laws and regulations that everyone can live with.

### *ENVIRONMENTAL ISSUES FACING THE FERTILIZER INDUSTRY*

Pending in Congress and the regulatory agencies today are initiatives which will affect the way we do business:

- **The Clean Air Act**
  Air Toxic Section—Ammonia is labeled as an air toxin requiring increased emissions regulation from manufacturing facilities.

  Accidental Release Section—Ammonia, nitric acid, sulfuric acid and phosphoric acid are identified as products requiring special regulation in both manufacture and storage.
- **Resource Conservation and Recovery Act**
  Regulation of radionuclides as they affect phosphogypsum stacks.

  Regulation of above-ground storage of hazardous materials, including ammonia, nitric acid, phosphoric acid and sulfuric acid.
- **OSHA Regulations on Air Contaminants Methods of Compliance**
- **Reauthorization of Hazardous Materials Transportation Act**
- **Groundwater Protection**
  Fertilizer runoff and Nitrates in Groundwater
- **1990 Farm Bill**
  Conservation Title—Low Input Sustainable Agriculture

### *CONCLUSION*

CF Industries' first priority in environmental matters is to impart to public officials that protection of the environment from incidents involving CF's assets is fundamental to our operation. In dealing with this list of environmental legislation and regulation, we will work with policymakers to attain objectives which are technically accurate, objective and with which we can comply in a reasonable timeframe. As the company works to meet its strict standards for health, safety and the environment, the Washington office will communicate our success to policymakers—utilizing the array of tools we discussed earlier. In this way, CF can be part of the solution to the environmental debate—helping to create an atmosphere of increased trust and respect for business.

## LISA: Fact and Fiction

*B. C. Darst*

**Potash and Phosphate Institute**

Low-Input Sustainable Agriculture (LISA) is on all our minds these days. My purpose is to look at LISA objectively, then offer an industry alternative.

First of all, we need to recognize that there are several positive impacts being made by the LISA movement.

- It has made people more sensitive to important environmental, conservation, technical and social concerns associated with agriculture.
- It has altered universities and other public agencies to new constituencies . . . those outside traditional agriculture.
- It has generated more financial support for related research and educational efforts.

- LISA's demand for information has stimulated universities to reassess their capacity to conduct systems research . . their ability to investigate complex interactions.
- It has increased attention to farm management research.
- It has created new opportunities for education . . . for farmers, agribusiness and the general public.

However, there has been a good bit of confusion about what LISA is, often because of the intense emotionalism attached to the use of fertilizers and pesticides and their influence on the environment. Also some of the proponents of LISA do not seem to understand potential implications on agriculture and the economy in general. In other words LISA does have some negative impacts.

- LISA is a conflict in itself. Can low-imput be sustained?
- LISA is the least appropriate system for operating with high fixed costs.
- Some LISA advocates do not accept the possibility that chemical pesticides can be produced that are harmless to all organisms except target pests.
- Some LISA advocates perpetuate a misunderstanding about soil fertility. They do not seem to accept the fact that crops remove essential nutrients that must be replaced.
- If LISA involves lower levels of inputs than the level which leads to minimum cost per unit of output, it cannot be self-sustaining in a mature agricultural industry.
- If U.S. agricultural producers are unable to compete for global markets, there will have to be further downsizing of the agricultural infrastructure, with resulting loss of jobs and economic activity.

A fact is that LISA is not necessarily based on science. Dr. Robert Hoeft, University of Illinois, brought that point out quite clearly when he said, "One serious flaw in the sustainable agriculture movement is that the changes proponents encourage are often based on testimonials rather than sound research."

Mr. Orville Freeman, former Secretary of Agriculture, also cited a weakness in LISA . . reduced production output . . . when he observed, "In the next two to four generations, world agriculture will be called upon to produce as much food as has been produced in the entire 12,000-year history of agriculture."

Dr. Don Holt, University of Illinois, seemed to place the entire LISA concept in proper perspective when he said, "Lower-input systems are more appropriate for less naturally productive land. Those who propose that lower-input systems are appropriate for all land are flying in the face of economic reality."

If we are to change the thinking of LISA advocates, and we must for the good of production agriculture, we must be willing to communicate with them . . . openly and objectively. Be aware that more than 100 organizations ranging from religious to rural advocacy groups support LISA. Their memberships number in the millions and their financial support in the hundreds of millions. They are a force with which we must deal.

Those who support LISA are well educated and highly motivated. They often misunderstand and oversimplify production agriculture, however. Some are also anti-technology.

Supporters of LISA claim that fertilizers and pesticides pollute the soil as well as surface and groundwater. They are said to be detrimental to farmer health and degrade food policy. Research does not support those claims. Yet, even farmers seem unsure if what they are doing is good for the environment.

In a 1988 survey reported in the *American Journal of Alternative Agriculture,* more than half of all conventional farmers did not feel environmentalists have greatly exaggerated the damages of nitrate fertilizer pollution.

The fact of the matter is that commercial fertilizers are more easily managed and more environmentally safe than alternate sources. For example, in Michigan studies, soil profile nitrate levels from manure and alfalfa (plowed under) were higher than those from commercial nitrogen fertilizer. In Minnesota, soil nitrate levels from hog manure were about four times as high when compared to levels from anhydrous ammonia.

We need to ask those who see fertilizer nitrogen as a pollutant to identify what the source of soil nitrogen is . . . natural, human and animal wastes, etc.? In other words, what was the base soil nitrogen level *before* nitrogen fertilizer was used? In an Oklahoma study, the natural reservoir was quite high, requiring five wheat crops before the researcher could measure a response to fertilizer nitrogen.

The real human health risks of nitrates in drinking water are low according to most surveys. Further, it is fairly easy to predict under what conditions nitrate will leach to groundwater, and Best Management Practices (BMPs) can minimize potential for pollution.

Proper nitrogen fertilization is a BMP. Used in balance with other essential nutrients and inputs, it enhances farmer profits, helps build soil organic matter and reduces nitrogen in the soil that might otherwise be leached into our groundwater supply.

BMPs for fertilizer and other inputs are developed through research and provide for optimum production efficiency and environmental protection. They are flexible and site specific. That is, they change from crop to crop, state to state, farm to farm, even soil to soil.

Fertilizers are essential to profitable crop production, accounting for about one-third of all crop yield in the U.S. and as much as 75 percent in some developing countries. Proper fertilization is a proven BMP. However, it must be balanced with other BMPs to be truly effective. According to The Food and Agriculture Organization (FAO) of the United Nations, "Fertilizer efficiency can be reduced by as much as 10 to 50 percent by improper management of other cultural practices."

Other BMPs such as conservation tillage and residue management reduce soil erosion and nutrient losses. As crop yields . . . and residue . . . increase, leaching losses are also minimized while water use efficiency increases. Good management . . . BMPs . . . is what production agriculture is all about. And it goes hand in hand with farmer profitability and environmental protection.

Our agricultural production system is the greatest in the world, yet a high percentage of the world's population is economically stressed in order to provide basic nutrition to its families. Can we honestly and morally accept production less than that provided through use of BMPs while thousands of people around the world are starving to death every day? I believe not.

We must get the attention of low-input advocates . . . to tell them about production agriculture. We must be effective communicators, to spread the facts:

- That our food is safe. According to the National Food Processors Association (NFPA), between 1980 and 1988, 93 percent of all food samples tested had no detectable residues.
- That there is no fail-safe system . . . in food production or any place else. Life itself is a risky business. This year, for example, you stand one chance in 11,000 of dying from a home accident . . . that's more than 20,000 Americans! How many will die from nitrogen fertilizer?
- That farmers must be driven by economics as well as environmental concerns. They receive only 25 cents out of your food dollar now. How much more can they be squeezed?
- That we cannot vertically diversify our farms to meet the requirements of low-input production. We don't have the labor force. In 1940 there was one farm for every 21 people in the U.S. Today there is only one per 115 people. Our agricultural production system has freed up 98 percent of the people to contribute in areas other than farming. We can't significantly reverse that trend without inflicting major damage upon our entire economy.

We must also accept the fact that the earth is finite . . .that growth of both population and physical output must eventually cease. We can't yet identify where that cessation will occur, but we can delay it and make life better for future generations by:

- Being better stewards of our soil.
- Protecting *and* improving our water resource.
- Sticking to the scientific approach rather than being swayed by scare tactics and emotion.

In summary, we in agriculture must be unified. Ms. Charlotte Sine, *Farm Chemicals* magazine, stated it well when she wrote, "Agriculture's position must be firmly based on sound science, not on perceived science as understood by those in consumer, environmental and media areas, who have other axes to grind." She went on to say that higher food prices and lower quality can result if agriculture fails to offer a coherent policy to protect the scientific basis for its productive ability.

We don't want to see the farmer dictated by those much less qualified than he. It can happen, though. Andy Stevens, *The Ohio Farmer,* concluded, "I see the possibilities of farmers losing control of the land they own. That is why as agriculturists you must take charge of your own destiny. If you don't, other will decide . . . "

Farmers must continue to be good stewards of our soil and water resources. We as an industry must continue to provide scientifically based responses to economic and environmental questions associated with crop production. We must be responsive to genuine concerns of others. But most of all, American agriculture must base its food production system on BMPs if we are to continue to feed ourselves and others.

Note: The attached might be of interest to you. We do win some! BCD

Atlanta Journal - Constitution, October 1, 1989

# Setting Record Straight on Nitrogen

### Virgil Adams

Some of us organic purists may not be as pure as we think. And some of those all-natural, chemical-free products we've been using in our gardens may not be as natural and free of chemicals as we've been led to believe.

I knew I was treading on dangerous ground when I left my own back yard and experiences and "went scientific" with those columns about nitrogen. Not that I am in any serious trouble or anything. It's just that I stirred up a hornet's nest of people who know a lot more about nitrogen than I do. I just wish I had heard from some of them before I started extolling the virtues of natural Chilean nitrate of soda.

What I said about it is true, as nearly as I can gather from the experts who wrote to me. There is just an awful lot I didn't say — in fact, could not say — even if the editor had given me all of the space in Home & Garden.

One letter was so well-written, so informative, so thought-provoking, I want to share it with you. I also talked with the author on the phone. He complimented me on the "vast amount of research" I had done and said the material I presented — such as it was — was basically correct. The only thing he chided me about was quoting the information — or misinformation — on that bag of natural Chilean nitrate of soda.

Bob Darst is vice president of the Potash & Phospate Institute, made up of 17 member companies and corporations and headquartered in Atlanta. The institute's business is research and education in plant nutrition. Mr. Darst has devoted a lifetime to this work.

Here is his response to what I said about one important plant nutrient:

"I read your column of August 20 [Chilean Nitrogen Passes Garden Test] with considerable interest and felt the need to send along some comments. You should be aware up front that I am an agronomist by training, and am a strong supporter of conventional agriculture. That said, let's talk about your column a few minutes.

"Nitrogen is indeed one of the most important plant nutrients from the standpoint of total requirements. However, some crop plants actually take up more potassium (K) than nitrogen (N).

"The earth's atmosphere is nearly 80 percent nitrogen, as you pointed out. That translates into about 75 million pounds of N over every acre of land on earth. That's a lot of nitrogen!

"An average U.S. corn crop removes nearly 6 billion pounds of N from our soils each year [in grain only]. That's about 25 pounds of nitrogen for every man, woman and child in this country. It's a good thing we have all that N.

"You also mentioned that nitrogen is a part of nucleic acids. The real significance of this fact was probably lost on most of your readers. The nucleic acids (RNA and DNA) are the 'blueprints' whereby genetic characteristics — both animal and plant — are transferred from one generation to the next. Without nitrogen, genetic differentiation would cease. Further, the process of photosynthesis would not be possible because N is a part of the chlorophyll molecule.

"Regarding your Chilean nitrate, it does contain contaminants in trace amounts, including boron, an essential plant nutrient. On the other hand, manufactured sodium nitrate — made by reacting nitric acid with either sodium chloride [table salt] or sodium carbonate — is free of such contaminants.

"The thing that fascinated me about your assessment of the acceptability of Chilean nitrate as an N source is that 'no chemicals were used' in its formation. Virgil, everything in this world is chemical: your bread, my golf clubs, newspaper print — there are no exceptions.

"Every chemical is safe; every chemical deadly. The relative degree of safety or danger is determined by exposure or chemical combination.

"The sodium in table salt is essential to our survival. Get it out of balance a bit and it can boil your blood pressure through the roof. Ingest what you can hold in your hand at one time and you're dead.

"Nitrogen, combined with other chemicals to form chlorophyll and proteins, sustains life; combined with toluene [an organic], it is TNT." —*Bob Darst, Atlanta.*

Comment: Thanks, Bob, for contributing to our growing knowledge of this important element.

The very name of the organization for which you work, the Potash & Phosphate Institute, reminds me that plants do not live by nitrogen alone. As you pointed out, some take up more potassium than they do N. And our vegetables and flowers, although well supplied with N, K and 14 other elements necessary for plant growth, would not do very well without a little phosphate, too.

So I thank you, sir, for agreeing to work with me on future columns about potassium and phosphorous. I believe it will be interesting and helpful to learn just how important these two elements are, their sources, how plants use them and what each contributes to the things we grow in our gardens and fields and serve on our dinner tables.

Finally, I thank you for helping us realize that, whether we are organic purists or conventional growers, we need to keep gardening in proper perspective and strive for balance in our beliefs and practices. You did that, Bob, with your "sustains life-TNT" comparison and the line, "Every chemical is safe; every chemical is deadly."

# Canadian Environmental Legislation

*Kenneth W. Reid*
**Potash Corporation of Saskatchewan**

## *INTRODUCTION*

The topic of this presentation is Canadian environmental legislation. when I first thought of how I might write a paper on such a diverse subject, I know how the student felt who, upon opening his examination paper found in the instructions the following:

"Questions 12-17 have an infinite number of solutions. Find them all and show all your work."

A paper of this type could not possibly describe all the environmental legislation which exists in Canada, nor do I think it would appeal to a general readership. It's hard to imagine a topic less likely to keep a reader awake than the listing of the details of the various pieces of environmental legislation which each of the various jurisdictions in Canada has created. Instead, the approach and trends of Canadian environmental legislation will be presented which, I think, is really what the Fertilizer Industry Round Table Organizers intended.

It is assumed that most of the readership is American and most are familiar with American environmental legislation. To make it easier for them to relate to this presentation, the Canadian situation will be frequently compared to that of the United States. It is intended, however, that the information will still be useful to readers from Canada and other countries.

I am a resident of Saskatchewan, one of Canada's provinces and an employee of the Potash Corporation of Saskatchewan, a potash producer. Consequently, my approach will be biased towards that province and that industry. However, an attempt will be made to keep the presentation sufficiently broad to apply to all industries and all jurisdictions in Canada.

Like the United States, Canada has a federal system of government with ten provinces which are roughly equivalent of states. There are also two large territories in the far north: the Yukon and North West Territories. The federal government has delegated most of the responsibility for environmental matters to the territorial governments. But in environmental matters, as well in all other matters in these territories, the federal government is supreme.

That is not the case in the provinces. Provincial governments are mainly responsible for environmental regulation in Canada and their legislation is not subject to the approval of the federal government. There is no Canadian organization equivalent to the EPA or OHSA. There is no Canadian legislation equivalent to RCRA, SARA, or the Clean Air Act, nor under the present system of government will there ever be.

It is interesting to examine how a government system, which on the surface appears to be similar to that of United States, produced a much more decentralized country. When Canada was formed in 1867, the constitution divided powers between the federal and the provincial governments. Residual responsibilities, that is those responsibilities not specified, were reserved for the federal government. Since environmental matters, except perhaps as reflected in public health, were not a concern in 1867, they were not mentioned in the constitution, and are clearly residual. One might expect then that the federal government would have the major responsibilities in this field. However, the constitution gave the provinces jurisdiction over resources and since most environmental problems result from some aspect of resource development, the provincial government has assumed the main responsibility for environmental legislation. The provinces jealously guard their jurisdiction over resources, and resist attempts by the federal government to legislate on resource matters, including attempts to regulate industrial discharges.

To sum up, Canada has two senior level governments, the provincial and the federal. Within their area of jurisdiction, each is supreme and they can be considered as equals. Except, as will be mentioned later, environmental legislation is mainly the prerogative of the provincial governments. The relative responsibilities of governments in Canada continue to evolve with the present trend being for the provincial governments to grow in power of the provincial and federal governments in Canada continues to be a major topic for public discussion.

## *FEDERAL LEGISLATION*

The federal government does have power to legislate on environmental matters within its jurisdiction. Since the federal government has responsibility for international or interprovincial matters and on fisheries as well as poorly defined power to legislate for the general public good, it has produced some potentially powerful environmental legislation. One of the oldest pieces of legislation is the Fisheries Act which allows the federal government to prevent discharges which will harm any waters inhabited by fish. Any proposed development on a international river requires a license from the federal government, and the federal government has a role in preventing an upstream province from causing damage to a downstream province because of pollution to a interprovincial stream. Protection of the Canadian portion of the Great Lakes is a federal responsibility as is the portion of the St. Lawrence River which forms the boundary between Canada and the USA.

These responsibilities, if fully exercised, could cause conflict between the federal government and the provinces which are considered the owners of the water. In practice, except for rivers important for producing salmon, the federal government does not assume a major regulatory role even in waters which are federal jurisdiction. The usual practice is to work with the provinces and, in the case of international streams, also the US and state governments to conduct studies and establish environmental objectives which are then left to the provinces to attain by producing and enforcing the required legislation.

The federal government regulates the transport of hazardous materials into and across Canada through the Transport of Dangerous Goods Acts which is essentially identical to the US CFR49. However, transportation of dangerous goods within a province is the responsibility of the provincial governments who have enacted legislation which accepts the federal legislation as being provincial.

The federal government has no role in occupational health except for federal employees or employees of interprovincial or international transportation companies. However, recently with the co-operation of the provinces, the federal government has established the Workplace Hazardous Materials Information System (WHMIS) which is essentially the same as the US Worker Right to Know regulations. In this initiative, as in most environmental legislation, the federal government prefers to act as a co-ordinator with the provincial governments having an equal say in the legislation and the enforcement being delegated to the provinces.

The regulation of the nuclear industry is an exception to the Canadian rule that the provinces have sole jurisdiction over resources. Since the nuclear industry is related to national defense, a federal responsibility, the federal government has been able to produce environmental regulations for the nuclear industry and enforce them independently of the provincial agencies.

Projects involving federal land or federal funding require that an environmental impact assessment acceptable to the federal government be prepared. There is a federal environmental assessment office which judges these proposals.

Recently the federal government has produced a Canadian Environmental Protection Act (CEPA) which is potentially powerful and will have an impact on industry particularly those using or producing toxic substances. CEPA gives the federal government authority to control the introduction into Canadian commerce of substances that are new to Canada as well as authority to require additional environmental data be produced on new substances and substances already in Canadian commerce. The federal government intend to use this Act to control all aspects of the life cycle of toxic substances. As the first step in this process, the federal government is proceeding to compile a Domestic Substances List which will identify substances which were produced or imported into Canada before 1987. Substances not on this list will require notification and assessment before they can be manufactured in or imported into Canada.

CEPA already been used to prohibit or control the use of substances such as PCB's, CFC's, asbestos, lead mercury, and vinyl chloride in Canadian commerce. CEPA prohibits or regulates the disposal of substances at sea. The lead content of fuel and the phosphate content of cleaning agents are now regulated by this legislation. CEPA allows the federal government to control air pollution from Canadian sources which cause an impact in another country. The government was hoping for an acid rain treaty with the United States when it enacted these provisions.

There is also provisions in CEPA which allows the Minister of the Environment to issue an emergency order to prevent or control environmental emergencies when a provincial government cannot or will not act. Constitutionality of this provision has yet to be tested.

An aspect of CEPA which has attracted attention is the possible penalty of up to 5 years in imprisonment and an unlimited fine for willfully damaging the environment. The Act allows a company officer to be held personally responsible.

In summary, the Canadian federal government has a limited role in environmental legislation. Although it does have jurisdiction in some areas, it prefers to delegate regulatory actions to the provincial governments. The present major environmental concern of the federal government are toxic substances and transboundary air pollution. The fertilizer industry in Canada is little effected by federal legislation.

## *PROVINCIAL LEGISLATION*

Except for the conditions mentioned above, provincial governments are completely responsible for regulating industry. Their regulations are not subject to approval from the federal government.

Most provinces have a Department of the Environment which sometimes includes responsibility for natural resources such as wildlife and forestry and sometimes includes occupational or public health and safety. All provinces have regulations governing industrial discharges into air, water and usually landfills. Discharge standards across the Country are generally similar, although sometimes the standards are stated in terms of concentration, sometimes in terms of mass per unit time, and sometimes in terms of mass per unit of production. Effluent and stack emission standards are established according to the capability of best practical pollution control technology for the industry in question. These would be considered minimum standards and they might be lowered if the discharge would cause non-compliance with ambient objectives.

In Saskatchewan for example, some of the ambient air quality standards for a 24 hour average are as follows:

Suspended particulate matter - 120 mg/m$^3$; $SO_2$ - 50 mg/m$^3$; and $NO_2$ - 200 mg/m$^3$.

Some water quality objectives are:

Nitrogen - 1.0 mg/L; phosphorus - 0.05 mg/L; dissolved oxygen - 5.0 mg/L and pesticides - 1/100 of the 48 hour TLM.

Saskatchewan does not have any fertilizer manufacturing plants. The following effluent and air emission standards for a new fertilizer plant came from the Province of British Columbia.

**Effluent (mg/L)**

| | |
|---|---|
| Suspended Solids | 50 |
| Ammonia (as N) | 0.5 |
| Phosphorous (as P) | 2 |
| Total Dissolved Solids | 5000 |
| Nitrates (as N) | 10 |
| pH | 6.5 - 8 |
| Flourides | 2.5 |

**Air Emissions (Annual Mean in mg/m$^3$)**

| | |
|---|---|
| Particulate Matter | 225 |
| Sulphur Dioxide | 0.02 |
| Flourides | 0.5 |

The potash industry in Saskatchewan is not allowed to discharge any effluent into any water body and instead uses a deep injection to dispose of waste brine. The standard for particulate in air emissions is 0.57 g/m$^3$, but there are no other air emissions standards for the potash industry.

Of the Canadian provinces, Ontario has the greatest number of environmental regulations and the largest bureaucracy to enforce them. This is a natural development since Ontario also has the greatest population density and the most industry of any Canadian province. Ontario has adapted a program called the Municipal/Industrial Strategy for Abatement which is aimed at eliminating all toxic contaminants from the province's waterways.

The rest of the provinces have not yet seen the necessity of developing environmental regulations to the same extent as in Ontario, but the environmental regulations of most other provinces have some unique aspects. The province of British Columbia requires the identification of the impact and fate of toxic substances before a permit is issued for their discharge. In Saskatchewan, the potash industry is being forced to re-examine the way it disposes of the large quantities of common salt which is the industry's solid waste. The regulatory agency is demanding acceptable decommissioning plans the waste piles be produced and has stated that no new mines will be permitted if they involve surface disposal of solid wastes.

Although all provinces are concerned about the disposal of toxic substances, only the provinces of Ontario and Alberta have any toxic waste disposal sites and, at present, these are closed to wastes originating in other provinces.

Only in Ontario do the regulatory agencies exhibit significant concern about pollution of ground water, and even there, has not reached the level which appears to exist in the United States. There is only marginal concern about agricultural residues in ground water. Except in the Great Lakes Basin, there is little concern about non point source pollutions and no attempt to regulate it.

In all provinces, a license is required from the Minister of Environment before any major new developments can be built. The license is issued only after the environmental impact of the project has been assessed and found to be acceptable. The environmental acceptability of projects depends very much on the philosophy of the provincial government. It appears that most provincial governments in Canada are more concerned about development than about environmental protection since there have been few projects rejected because of environmental impact.

From a perspective, north of the 49th parallel, a major difference between Canada and the U.S. is the approach to enforcement. Rarely are courts used, and seldom are fines imposed in Canada for violating environmental regulations. The usual approach is a negotiated agreement between the industry and the regulatory agency. If negotiations fail, a Ministerial Order is issued which usually gives the industry some time to comply with the order.

Any fertilizer company concerned about the impact Canadian environmental legislation will have on its operations is advised to consult with the appropriate provincial department of the environment. Probably all the environmental licenses that are required to operate will be obtained from this agency.

## *THE PUBLIC*

Although the public does not make environmental regulations, they cause governments to make these laws. The public's present concerns will be reflected in future environmental legislation, and therefore, in the context of this paper, a description of the public opinion in Canada on environmental matters is worth a brief mention.

On the whole, Canadian citizens appear less concerned about environmental matters than those of the US probably because Canadian citizens have more opportunity to escape to natural areas and therefore, environmental problems seem to involve them less on a personal level. However, the environmental concerns of the Canadian public have never been higher and, over the past 3 years, public opinion surveys have consistently found that environment is a major concern taking precedent over such items as the economy of unemployment. The action of Canadian governments are beginning to reflect this concern.

Canada has a number of environmental organizations including Canadian chapters of some American organizations, but, they are not as powerful as they appear to be in the United States. Only recently have citizen groups begun to use the courts to achieve environmental goals. As a rule, Canadian appear to be more respectful to authority than Americans and are more hesitant to challenge it in the court or in other ways.

Because of the inability of power of the federal government to dictate a national environmental program, one province, even though it contains most of the population, is not able to force its environmental agenda on another. Thus, although organic farming is becoming fashionable in Canada, there is no danger of the largely agricultural province of Saskatchewan being forced into a LISA type program to suit the demands of the largely urban citizens of Ontario.

## Ammonia Regulation

*Rusty Walker*
**Freeport-McMoRan, Inc.**

Ammonia regulation did not begin with the disaster in Bhopal, India, but that tragedy accelerated the pace of regulatory activity on many fronts. Title III of the Superfund Amendment and Reauthorization Act (SARA), the Congressional response to Bhopal, led the way.

Section 304 of Title III requires local government to plan for emergency response and Sections 311 and 312 informs government and the public as to the volumes of hazardous substances made, stored, and transported. Ammonia is one of the highest volume hazardous substances. Title III's Section 313 reporting requirements confirmed that ammonia is also one of the highest volume "toxic" air pollutants designated by the Act. The reporting discussion and public/regulatory response has heightened concern about ammonia with effects on many regulatory programs from the U.S. Coast Guard to Department of Transportation (DOT), Occupational Health and Safety Administration (OSHA), Environmental Protection Agency (EPA), and State regulatory bodies. It is complicating government and industry's ability to maintain the appropriate regulatory approach to ammonia as a primarily acute hazard.

I will organize my brief overview by distinguishing acute/catastrophic regulation from chronic. I will address the safety, health, and environmental aspects of ammonia regulation but these distinctions are increasingly artificial and blurred in the regulatory scheme. Some blurring is appropriate such as in emergency response. Industry and local governments should cross traditional regulatory boundaries to work together more than in the past. Some of this trend, however, is inefficient overlap such as the various agencies that must be notified of spills and leaks each with its own time and circumstance requirements.

### *AIR - ACUTE/CATASTROPHIC*

The fertilizer Institute (TFI) was advised in 1985 that DOT might reclassify ammonia as a poison gas. A TFI Task Force recommended that DOT reclassify ammonia as a "corrosive gas" and require that containers be labeled with "inhalation hazard." At the time of this presentation it appears that this issue has been favorably resolved. (Later in November, however, the comment period was extended based on environmental group pressure so the issue may be more open that hoped).

The Coast Guard published Liquified Hazardous Gas Waterfront Facilities regulations in 1988 proposing to expand requirements for ammonia docks more like those for LNG. Industry commented on the inappropriateness of many of these proposals which seemed to be based more on fire hazards. As far as this author was able to determine, this proposal and comments are still being studied by the Coast Guard.

OSHA has implemented an increased emphasis on catastrophic potential/response readiness in its routine inspections. Pressure vessels, for example, are under greater scrutiny. Training requirements and qualification of emergency responders was made more stringent in 1989. More requirements are likely from this Agency with potential for turf issues between OSHA and EPA (see Clean Air amendment proposals below).

As indicated above, Title III required industry to identify its designated hazardous substances to newly created community response organizations mandated by the Act and to local fire departments. Notifications also have to be made to these same local organizations of significant spills and leaks and the response agencies are mandated to develop response plans for these substances at specific facilities. Unlike other aspects of Title III, the planning burden is on the communities. The efforts have generally resulted in better communication and planning between industry and local government with more mock drills, better notification procedures, and the like. There is increased awareness and concern. One aspect of Title III which is likely to get more emphasis in the future is the requirement that local response organizations study transportation routing for hazardous substances. This may result in impacts on the movement of these substances, including ammonia.

The U.S. Congress is in the throes of reauthorizing the Clean Air Act. A significant edition to this Act will deal with sudden and accidental, or catastrophic accident potential. It will go beyond Title III in many ways and put the burden for planning more on industry. As proposed by several Congressmen, it includes formal risk assessment with computer modeling protocols. Mandated industry prevention programs after identification and risk assessment are also part of most proposals. EPA may be given more responsibility to inspect and respond to major releases of toxic substances and several bills propose the creation of a Chemical Hazard Investigative Board similar to the National Transportation Safety Board. This new

Board would investigate accidents, report and regulate (including things like overflow control, alarms, monitors, and containment). It would be the most sweeping new authority related to catastrophic issues ever and is likely to pass in some form.

### *AIR-CHRONIC*

In this area, OSHA moved to a Short Term Exposure Limit of 35 ppm for 15 minute exposure for ammonia which is considerably tighter than its previous standard of 50 ppm for eight hours. For areas higher than this level of exposure, the new regulation would require engineering control instead of respirators. In the ammonia industry, there are apparently few areas with this level of exposure and those few areas require minimal human contact. The traditional use of respirators is much more appropriate than extremely expensive engineering controls in such areas. The proposed use of engineering controls is more appropriate where human contact is routine. At the time of this presentation, industry is hoping that the Agency might recognize the need for some provision for continued use of respirators in these few areas.

Of greater potential impact is the growing adoption by States of air toxic regulations including standards based on factoring of the worker based TLV's (Threshold Limit Values developed by the American Conference of Governmental and Industrial Hygienists). The TLV for ammonia is 25 ppm for an 8 hour exposure typical of workers. The states are taking this standard and factoring it for exposure to the public of 24 hours/day, 7 days a week and adding an additional safety factor. The most common factoring results is 1/42nd of the TLV but some proposals go as far as .25 ppm ammonia outside the plant boundaries.

The states' extreme approaches, in part, resulted from the difficulty EPA had establishing standards for air toxics. EPA was mandated several years ago to study many possible air toxics to establish standards but has done so for less than ten. Lack of human exposure data is just one of the Agency's handicaps. Frustration with EPA delays, coupled with the growing public concern over air toxics from accidents and reporting under Title III, has forced many states to the easy alternative of factoring workplace TLV's. This puts the burden of proof on industry to show that factored TLV's are not appropriate rather than requiring state agencies to do the science necessary for such standards.

Thirty-seven states have policies and/or regulations dealing with air toxics and most lists include ammonia. Several states are still in the inventory stage collecting data. A range of recent state experience follows, offered with the cavaet that all is in a state of flux.

Oklahoma adopted 1/10th the TLV. The State will determine compliance until a plant needs a permit and then modeling will be required. Iowa has proposed a 1/100th of the TLV but this is being appealed and is in review by the legislature.

In Louisiana, 1/42nd of the TLV is a guideline for permitting. The State is using it as part of an overall effort to reduce emissions. That effort includes new requirements to reduce designated toxic emissions by 50 percent in three years. Alaska has used, in permit matters 1/42nd of the TLV. One company had problems with 1/42nd based upon modeling and is now continuously monitoring around its site. The State is proposing an ammonia standard of 20 ppm for 15 minutes and 0.5 pm for 8 hours.

Ohio uses 1/42nd of the TLV for screening. A 13-ton ammonia spill resulted in a fine, modeling and risk assessment.

TFI's initial response to all this activity was first to contract with a consultant to summarize the literature on ammonia. This report is near completion and supports the industry position that ammonia is an acute, not a chronic hazard, and that 1/42nd of the TLV or tighter standards are wholly inappropriate for a substance that is at worst an irritant at low levels. This information will be used by TFI members to work with state regulatory agencies and seek more reasonable approaches.

The Clean Air Act Amendments mentioned above under acute regulation are also likely to impact regulation of ammonia from a chronic standpoint. If ammonia is on the final list of substances covered by the toxic portions of the regulation, EPA will do a survey of the industry to see who does the best job of control of emissions and adopt that as the standard. If such a survey is not possible or productive, the Agency will develop its own procedures, modifications history, etc. Regardless of the difficulties, however, if ammonia makes the list, there will be mandated control technologies and/or standards relatively soon after the Clean Air Act is re-authorized and these will result in substantial expenditures by the industry.

### *WATER REGULATION*

**Surface Water**—Ammonia has not been a significant drinking water problem. It is, however, one of the most prevelant surface water pollutants from an aquatic species perspective. EPA moved in 1980 to list ammonia as a water toxic and develop numeric standards. TFI and others successfully averted such a single national standard because of the difficulty of adopting single numbers for a substance with impacts that vary widely depending upon its state (ionized vs. unionized), pH and temperature of receiving waters, salt or fresh water characteristics, warm or cold water fish species, etc. Another difficulty was that industry was only a small part of the total ammonia discharge which is primarily from municipal/sewage treatment works. At the federal level ammonia remains a nonconventional pollutant with each state adopting its own approach. These range from narrative standards like Oklahoma's that simply require no toxicity, to numeric standards, as in Florida, which limits unionized ammonia to 0.02 ppm. Current practice is to regulate ammonia toxicity through bioassay techniques in association with waste water discharge permitting.

Increased attention to ammonia in surface water can be expected as part of an overall increase in attention in surface waters.

**Groundwater**—Ammonia has not generally been judged to be a significant groundwater problem. There is concern about nitrate in groundwater and ammonia can be a contributor to this. EPA is surveying the nation for nitrate problems and there may be increased attention focused on ammonia and nitrate resulting from the survey. This concern may fuel other efforts such as the growing call for Low Input Sustainable Agriculture (LISA), for warning labels on fertilizer, etc.

In summary, most regulatory agencies have appreciated the uniqueness of ammonia and the need to regulate it differently than most other chemicals. However, the pressure is increasing for more specific regulation of toxics, and ammonia is usually included in any general listing. Industry needs to support reasonable regulation through strong emergency prevention/response efforts and reasonable emission reductions and recycle/reuse. We need to take our programs to the public and continue to work with the regulatory agencies to strike the necessary balance.

# Wednesday, November, 1, 1989

## Session IV
## Moderator:

## Edwin Cox

## Balanced Fertilization and the Environment
### Adequate Phosphorus & Potassium Help Protect Water Quality

*W. K. Griffith*
**Potash & Phosphate Institute**

Nitrogen, along with potassium, is taken up in larger amounts by crops than any other nutrient. It is essential to plant and animal life and a major constituent of amino acids, proteins, nucleic acid and chlorophyll. Crop responses to nitrogen are universally recognized and the role of nitrogen as an important and essential production input to achieve maximum economic yields is justified. It is the super nutrient.

Fertilizer nitrogen use has increased rapidly from 2.7 million tons used in 1960 to over 11.4 million tons in 1986 in the U.S. This increase mirrors the equally spectacular rise in agriculture production during that same time. No one can argue that to put limitations on nitrogen application rates per acre will put a ceiling on crop yields and reduce the flexibility farmers have to manage for MEY and increased profit potentials. However, there is a growing concern about fertilizer nitrogen as one of the nonpoint sources of Nitrate-N which can enter groundwater supplies and become a potential water quality problem.

### *NITROGEN SOURCES*

*Animal Manure.* Addiscott (1988) summarized the research from Rothamsted over the past century and concludes that all the nitrogen that becomes available to crops is also vulnerable to leaching. It makes no difference whether this nitrate originates from a chemical fertilizer, organic matter sources, or the breakdown of organic matter in the soil. They have observed leakage from a pool of decomposable nitrogen in arable soils which breaks down slowly with time. They suggest scientists should expect to find some base level of nitrate in soils at any one given time. THEY HAVE FOUND THAT WHILE ANIMAL MANURE CAN BE AT LEAST AS EFFECTIVE AS CHEMICAL FERTILIZER IN IMPROVING YIELDS IT IS ALSO MORE OF A POLLUTION RISK. This is because plots receiving manure regularly contain more nitrate-N in the soil after harvest in the autumn than plots receiving chemical fertilizer. There is more organic-N for microbes to break down and this comes from both past and current year additions of manure.

*Forage Legumes.* One of the prime reasons for including forage legumes in rotation with non-legume crops in low input systems is the contention that legumes will reduce the need for fertilizer-N and minimize nitrate-N losses to groundwater. The perception being that legumes do not release nitrate to groundwater. Russelle and Hargrove (1989) have written an excellent review and have summarized research conducted on this topic. Their concluding paragraphs state:

"NITRATE LEACHING HAZARD ASSOCIATED WITH ORGANIC SOURCES OF N SUCH AS ANIMAL MANURES OR LEGUMES CAN BE SIGNIFICANT. Successful use of these N sources to supply adequate N to a growing crop while minimizing losses requires equally careful management as with inorganic N sources. Simply replacing fertilizer-N with these sources will not ensure a reduction in nitrate leaching. Estimates of the mineralization rates of these sources are needed in order to ensure timely application of appropriate rates. Organic-N sources often result in larger amounts of residual soil-N after cropping than fertilizer-N sources. Management practices such as cover cropping with a non-legume to remove some residual N might be appropriate in many situations.

Best management practices for low-input systems are evolving, but to minimize ground water contamination, they will require equal, if not greater, levels of management compared to fertilizer-N based production systems. In the final analysis, development of management strategies that satisfy both ecological and economic concerns will support a vigorous, sustainable agriculture system."

*Fertilizer Nitrogen.* Commercial fertilizers are the most controllable source of nutrients for crop production. Through judicious selection of rates, placements, sources, and application times it is possible to supply nutrients reasonably close to the economically optimum level. By contrast, it is difficult to fine-tune the amount, or timing, of N release from animal manure, forage legumes, or other types of organic wastes (Fixen, 1985). This difficulty increases environmental risk.

Nitrogen uptake by plants is independent of nitrogen source as each source is transformed in soils through biological actions (the nitrogen cycle) into exactly the same plant available forms. The nitrogen requirement for a certain crop production level is not modified by selection of alternative nitrogen sources. Therefore, efficient and economical nitrogen management decisions must be based on the availability of a particular nitrogen source, the amount of plant available nitrogen in the soil, the yield potential as determined by crop management and soil capability and nitrogen application methods and timing for efficient utilization.

## *GAP BETWEEN NITROGEN AND P-K USE WIDENS*

Adequate supplies of phosphorus and potassium are of special concern when optimum N rates for profitable crop production systems and the environment are considered. Correct balance in fertilizer use leads to optimum production, greater nutrient efficiency, and reduced risk that nitrogen will be lost to ground water. The current ratio of NPK use raises some questions about nutrient balance (Table 1). Nitrogen use has increased at a much faster pace than P or K.

Today the N-P-K ratio is probably too wide, based on soil fixation, nutrient uptake of major crops, and the percentage of soils testing medium or less in P and K. Unbalanced P and/or K with N can be an important limiting factor where soil test levels are in the medium or less range and where P and K must be added for both maintenance and production. Table 2 shows the soil test P and K levels for several large agricultural states.

## *PHOSPHORUS AND POTASSIUM BOOST NITROGEN EFFICIENCY*

A long term corn study shows the importance of maintaining adequate P and K levels, along with nitrogen, for yield and nitrogen efficiency. To the farmer this means a more profitable crop and one which has less unused nitrogen subject to leaching and contamination of groundwater (Table 3). Response to P and K were evident (PPI, 1986).

The first three years of the test which resulted in greater N efficiency as the bu/lb of applied N increased from .84 without P-K to .96 with P-K. A key factor is the increasing amount of unused N as P and K were omitted the final six years. Unused N averaged 56 lb N/year in the second three-year period. This N subject to leaching and presents a potential risk to groundwater. In addition, the farmer would suffer as economic loss in terms of lower yields, and, in this case, over $11/a/year for the unused N. During the final three years where no P or K was added, there were enormous yield losses and N fertilizer use was highly inefficient. Note that where P and K were applied annually N efficiency was maintained, or slightly improved, during the nine years.

Table 4 & 5 shows examples from Illinois and Indiana where balancing N applications with adequate P and K results in better yields and more efficient utilization of nitrogen. Over 20 to 30% of the nitrogen was unused when P and K were not applied. When P and K applications were brought into balance with fertilizer N, the growing crop required more N than was applied and the potential environmental impact eliminated. This is seen in both examples.

Similar observations can be cited for cotton, wheat, rice—or any other crop requiring nitrogen fertilizer and where a yield response to P and K is expected. In Kansas, for example, a P application almost doubled the number of bushels produced per pound of N (Table 6). Each rate of P increased N efficiency. This is very significant in the big wheat states of Colorado, Kansas, Montana, Nebraska, N. Dakota, Oklahoma, S. Dakota, and Texas where from one-half to three-fourths of the soils test medium or less in P. At the same time, average P applications are well below optimum (according to most recent USDA statistics the 51 million planted wheat acres in these states received an average of only 13 lbs of $P_2O_5$/a), which means that quite often the applied N is not being used most efficiently. The result is more N left in the profile as a potential groundwater problem. Nitrogen from the soil to supplement the fertilizer N was needed in increasing amounts as phosphorus rates increased which suggests that a higher N fertilizer application rate may have been needed for most profitable yields and environmental protection.

## *NITROGEN EFFICIENCY AND BEST MANAGEMENT PRACTICES*

To help assure optimum benefit from nitrogen fertilization with the least impact on the environment requires the use of best management practices (BMP's) for all controllable production factors. All the benefits of BMP production which include quicker ground cover, more crop residue, greater root growth and more leaf area will help improve nitrogen efficiency, reduce erosion, and minimize potentially negative environmental effects. Table 7 summarizes research from several locations for corn. The results show the impact various growth factors have on increasing yields and nitrogen efficiency. As these production practices are put together to achieve a BMP system, nitrogen efficiency improves and the possible detrimental effects on groundwater quality decreases.

## *SUMMARY*

Farmers must retain their freedom to use optimum nitrogen rates for each specific crop yield goal.

Any mandatory limit on nitrogen use will put a ceiling on yield levels, limit the research incentives to develop new crop production technology, and take away from the farmer his management flexibility to use BMPs. At the same time, it is the responsibility of the farmer, and those who serve him, to see that nitrogen is applied accurately and at rates which fit his yield potential. In doing this, he needs to develop an MEY production management system, using the proper combination of all controllable inputs, which will give the highest level of nitrogen efficiency possible for his soils and climate. When farmers combine agronomic and soil conservation BMPs, they can rest assured that fertilizer nitrogen will contribute minimal levels of nitrate-N to groundwaters, and they will benefit from the best of both worlds—A cleaner environment and a more productive and profitable agriculture.

Note: For calculations in this paper the following were used:

1.3 lb/bu N taken up by corn
1.88 lb/bu N taken up by wheat
$.20/lb cost for nitrogen

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**TABLE 1**
**RATIO OF N: $P_2O_5$: $K_2O$ USED IN THE UNITED STATES.**

| Year | N | $P_2O_5$ | $K_2O$ |
|---|---|---|---|
| 1960 | 100 | 94 | 79 |
| 1970 | 100 | 61 | 54 |
| 1980 | 100 | 48 | 55 |
| 1986 | 100 | 40 | 48 |

**TABLE 2**
**MOST RECENT SOIL TEST P AND K SUMMARIES FOR 10 STATES.**

| **State** | **Phosphorus** | **Potassium** |
|---|---|---|
| | **percent of tested soils in med. or less range** | |
| Arkansas | 68 | 68 |
| Georgia | 54 | 80 |
| Illinois | 50 | 64 |
| Iowa | 44 | 39 |
| Minnesota | 34 | 59 |
| Mississippi | 53 | 53 |
| Missouri | 55 | 76 |
| Ohio | 38 | 53 |
| Oregon | 49 | 34 |
| Pennsylvania | 69 | 60 |

**TABLE 3**
**EFFECTS OF OMITTING P&K ON CORN IN A LONG TERM MARYLAND STUDY.***

| | **1974-1976** | | **1977-1979** | | **1980-1982** | |
|---|---|---|---|---|---|---|
| | +PK | −PK | +PK | −PK | +PK | −PK |
| Yield (bu/a) | 153 | 134 | 149 | 74 | 165 | 31 |
| Nitrogen bu/lb appl'd. | .96 | .84 | .93 | .46 | 1.00 | .19 |
| N balance sheet;** Soil supplied(−) or unused fert. N+) | −39 | −14 | −34 | +56 | −55 | +120 |
| Lost value of unused N | | | | $11.20 | | $24.00 |

* 160 lb/a N used annually with or without 160 lb/a $P_2O_5$ and $K_2O$

** Lbs N/a uptake (above ground portion) more than (−), or less than (+) lbs fertilizer N/a applied.

**TABLE 4**
**EFFECTS OF BALANCING N WITH P & K ON CORN YIELD AND NITROGEN EFFICIENCY IN ILLINOIS. (Wagner, 1980)**

| **Fertilizer Level lb/a** | **Yield bu/a** | **Nitrogen Efficiency bu/lb N** | **N Balance Sheet soil (−): unused (+) lb/a** | **Value unused N $/a** |
|---|---|---|---|---|
| 180-60-0 | 96 | .53 | + 55 | 11.00 |
| 180-0-90 | 111 | .60 | + 36 | 7.20 |
| 180-60-90 | 143 | .79 | − 6 | --- |

## TABLE 5
## EFFECTS OF BALANCING P & K ON CORN YIELDS AND NITROGEN EFFICIENCY IN INDIANA.

| Fertilizer Level lb/a | Yield bu/a | Nitrogen Efficiency bu/lb N | N Balance Sheet soil (−): unused (+) lb/a | Value unused N $/a |
|---|---|---|---|---|
| 200- 0- 0 | 127 | .64 | + 35 | 7.00 |
| 200- 50- 0 | 139 | .70 | + 19 | 3.80 |
| 200- 0- 50 | 147 | .74 | + 9 | 1.80 |
| 200- 50- 50 | 162 | .81 | −11 | --- |
| 200-100-100 | 167 | .84 | −17 | --- |

## TABLE 6
## ADEQUATE P INCREASES WHEAT YIELDS AND IMPROVED N USE EFFICIENCY IN KANSAS. (PPI, 1986)

| N | $P_2O_5$ lb/a | Yield bu/a | Nitrogen efficiency bu/lb N | N Balance Sheet soil (−): unused (+) lb/a |
|---|---|---|---|---|
| 75 | 0 | 35 | .46 | + 9 |
| 75 | 20 | 51 | .68 | − 21 |
| 75 | 30 | 56 | .75 | − 30 |
| 75 | 40 | 61 | .81 | − 40 |
| 75 | 50 | 64 | .85 | − 45 |

## TABLE 7:
## THE EFFECTS OF SEVERAL PRODUCTION INPUTS ON CORN YIELD AND NITROGEN EFFICIENCY FROM VARIOUS LOCATIONS

| Production Factor | Yield bu/a | Nitrogen Efficiency bu/lb N | N Balance Sheet Soil (−): Unused (+) lb/a | State |
|---|---|---|---|---|
| Rotation: | | | | |
| continuous | 105 | .88 | + 14 | |
| rotation | 120 | .96 | − 6 | (Dunphy, 1981) |
| Irrigation: | | | | |
| without | 127 | .51 | + 85 | |
| with | 214 | .86 | − 28 | (PPI, 1984) |
| Planting Date: | | | | |
| late May | 132 | .66 | + 28 | |
| early May | 163 | .86 | − 12 | (Indiana) |
| Hybrid: | | | | |
| bottom 5 | 149 | .60 | + 106 | |
| top 5 | 250 | .83 | − 25 | (Wright, 1980) |
| Population: | | | | |
| low (12,000) | 155 | .52 | + 39 | |
| high (36,000) | 231 | .96 | − 60 | (Wright, 1980) |
| Compaction: | | | | |
| compacted | 123 | .62 | + 33 | |
| not compacted | 167 | .84 | − 17 | (Steinhardt, 1982) |
| pH x P: | | | | |
| low pH, low P | 90 | .60 | + 33 | |
| high pH, high P | 138 | .92 | − 29 | (PPI, 1988) |
| P Placement (row): | | | | |
| no $P_2O_5$ | 143 | .64 | + 39 | |
| 35 lb $P_2O_5$ | 159 | .71 | + 18 | |
| 70 lb $P_2O_5$ | 165 | .73 | + 11 | (PPI, 1988) |
| K × Planting Date: | | | | |
| no K × late | 125 | .52 | + 78 | |
| no K × early | 142 | .59 | + 55 | (PPI, 1988) |
| K × late | 156 | .65 | + 37 | |
| k × early | 170 | .71 | + 19 | |

# Environmental Audits of Fertilizer Blending Plants

*John L. Medbery*

*Consultant*

In the past few years, more and more regulations have been enacted by the various states for the protection of water resources. These have become increasingly stringent. They focus largely on the farm supply businesses in the rural areas. The concerns center mostly on the potential for contamination of ground water and surface water by fertilizers and crop protection chemicals.

Several states, in making toxicology studies, have found excessive levels of nitrates and chemicals in well water near blending plants. This is usually attributed to the practice of rinsing or emptying application equipment on the ground. Accidental spills still occur all too frequently and run-off from plant sites during rain events also contribute to this problem.

A program of on-site environmental audits, preferably performed by a knowledgeable outside authority is an excellent way to identify potential trouble spots. These are things that the local operators have become so accustomed to seeing that they cannot envision the possibility of an event that will result in contamination. We know, all too well, that given time and circumstances, Murphy's Law will prevail. When the oil facility at Valdez was opened fifteen years ago, an old sourdough standing at the fringe of the celebrating crowd was heard to say, "They'll hit a rock someday, and this damn stuff will be all over the place." How prophetic! Murphy's Law has been proven again! The purpose of an on-site inspection is to foresee, as much as possible, WHAT MIGHT HAPPEN and then compel corrective or preventive actions.

With this goal in mind, the inspector can proceed in several ways; however, my personal belief is that "one picture is worth a thousand words. " The camera is my most useful tool. As I shoot film, I record the shot number and a brief description of the scene on a log. This later becomes the basis of an illustrated report. Follow-up is easy, because all that is necessary is to compare the then-current scenes with the photo in the report.

The various photos are correlated to a site plan drawing by 'identification numbers and directional arrows on the drawing. Figure 1 is an example of a site plan with photo views indicated.

The photos are taken to illustrate a number of situations. These include: Best Management Practices (BMP) as carried out by the farm center, or lack of BMP concern by a particular location. They also will portray potential trouble spots; that is a situation where Murphy's Law is just waiting to manifest itself.

Still another use of the photos is to monitor the damage following a spill event or where surface run-off has penetrated a nearby field or water course. In a number of situations, I have followed the natural drainageway for up to a mile or more just to see what might happen if a spill occurred, and to locate a suitable site for blocking the flow and recovering the spilled material.

Many midwestern states now require each farm center location to have an emergency plan in place. This involves pre-planning for almost any contingency including an ammonia line rupture, broken UAN piping, fire in the chemical storage building, etc. The local fire department is asked to visit the site. They are then familiarized with the surface run-off pattern, the hazardous or toxic liquids, gases and flamables at the plant, the accessibility through locked gates, and the availability of water. Emergency telephone numbers of all key employees are conspicuously posted at the plant entrance. Gas mask and oxygen breathing equipment storage locations are identified. All emergency equipment is inspected and its condition logged.

Piles of sand for blocking drainageways are located, as are shovel loaders for placing the sand. Outside contractors with earth moving equipment are also contacted and apprised of their possible need in event of a major spill, or to block run-off of water used to control a chemical fire.

Even the Valdez disaster could have been minimized if a spill control plan was in place and had been implemented promptly. Quick action is essential. Preplanning is necessary. Practice drills are required.

Figure 2 is a layout drawing of a typical plant site, where the drainage directions are indicated by arrows. The natural surface flows go to a small stream which enters a recreational lake. To prevent spilled liquids or surface run-off containing dissolved chemicals from entering the lake, an emergency impoundment pocket has been provided. The circled numbers indicate where photos were taken. This type of drawing is standard in each plant's Emergency Plan, but in that case the numbers indicating photo shots would be omitted.

A plant environmental audit should include a map showing where the farm center is located within the nearby community. Figure 3 shows a plant location in the North Henderson Township of Mercer County, Illinois.

Figure 1 is a plot plan of the plant site itself. As is customary, the environmental audit report will discuss all aspects of the scenes photographed and make a risk assessment for the plant. Specific recommendations are included. Best Management Practices to minimize loss are always stressed.

One of the most frequent causes of surface water contamination, and possibly of ground water contamination too, is the massive spill of direct application nitrogen solution. Diking around the storage tanks is now an accepted practice for controlling spillage. The diking systems have to be designed and built properly if they are to be effective. If concrete is used, the floors have to be thick enough and strongly reinforced to resist cracking. Stresses caused by filled tanks and by freezing soils have to be countered. Joints for expansion are necessary, but they must be sealed with a flexible caulking material to provide a liquid barrier.

A curbed slot is commonly provided to enclose a vehicle which may be delivering solution to the tank farm, or which may be in the process of being loaded. Hose rupture is a cause of concern as is over-flowing a transport or application vehicle. The curbing on the sides and the retention humps at the ends must be high enough to contain a surge and a drain of proper size must be provided to allow the spillage to flow into a recovery sump within the main diked tank farm site.

Outlet valves on tanks must be provided with locks, and they should be locked in the closed position whenever not in use. Also, gauge tubes should be equipped with locking valves. These, too, should be locked closed except when gauging is being done.

All UAN tanks should have the TFI designed decal cautioning against cutting or welding on these tanks unless they have been emptied,thoroughly cleaned and inspected before beginning such work. These "Caution to Welders" labels should be kept fresh and must be replaced promptly following repainting of any tank's outer surfaces. IMC has a similar label of its own design.

Galvanic corrosion is a cause for concern. Plugs and fittings should be either 300-series stainless steel or plastic. Malleable iron plugs and nipples should not be used with aluminum tanks or piping components.

Almost all farm centers handle ammonia. Ammonia is safe when all equipment is properly maintained and the safety rules are followed explicitly. Color coding of the liquid and vapor lines is an important safety precaution. Weeds and dry grass must not be tolerated in the vicinity of storage tanks. All applicator equipment must be inspected on a regular schedule and preventive maintenance performed routinely. Checking of pressure relief valves and hoses is especially important. Safety towing chains and running gear must also be inspected. Gas masks, protective clothing and flushing water must be readily available for quick use in event of an accidental spill.

Chemicals stored at the plant must be kept under close control to ensure adequate inventory and to prevent pilferage. The local operator, in conjunction with the fire department, must be aware of toxic fumes that may evolve during a fire, and must be prepared to contain run-off that would result when water is applied to the burning warehouse.

The disposal of empty chemical containers is a problem. Much of this difficulty can be avoided by use of bulk chemicals stored within their own outer containment vessel. These can be covered to prevent rain water from entering.

Mini-bulk is another solution to the container disposal problem. These containers are returnable to the supplier. They can be handled by forklift trucks, and can be transported in the plant's own light truck.

Small metal cans can be triple rinsed and flattened all in one process. One device for accomplishing this is marketed under the name "Captain Crush"

Rinsates from applicator equipment must be kept separate. That is, residues of herbicides for grass-type plants, such as corn, must not be mixed with residues of herbicides designed for broad-leafed plants such as soybeans. Separately labeled, and preferably color-coded rinsate tanks must be provided.

At many locations, chemical impregnation of fertilizers is a standard practice. The crop protection chemical is pumped to the mixer and sprayed on to the tumbling bed of fertilizer as it is being blended. After herbicides have been added, it is especially important to control all spillage and to prevent mixing of impregnated products. For instance, a blend treated for corn could damage soybeans.

Mixers and application vehicles must be completely emptied and all spillage recovered immediately and combined into the shipment. I have urged blenders to install their equipment on a full concrete slab and to provide concrete at the loading site so that clean-up can be accomplished quickly and thoroughly as each shipment is prepared and loaded.

Airborne dust at the load-out point is also a problem. This has been successfully controlled by several blenders by spraying a small amount of UAN solution on to the blend as it is mixed. One gallon per ton is adequate. We also recommend the use of skirts at the discharge of the load-out conveyor. This reduces the amount of dust that is released. Also, a twin chute arrangement has proved helpful. The long chute is swung into place for low vehicles and the short one is used for high-sided equipment.

Spilled fertilizer at the receiving conveyor can also be a source of contamination. As the fertilizer spillage is dissolved by rainwater, it is carried via the natural drainage flow into nearby fields or other environmentally sensitive areas. It is essential that all spillage be cleaned up immediately following each unloading event. Where dump truck delivery is involved, a concrete slab at the dump site would facilitate quick and complete recovery of material and would also prevent contamination resulting from mixing of different materials.

Figure 4 is a layout plan of a blend plant site where surface run-off rich in dissolved fertilizers, and possibly herbicides, has affected crop land on two sides of the triangular shaped property. On the west side, the field has a low surface in two spots, and rain-water from the plant has pocketed there. Although a crude barricade of old railroad ties backed by gravel was provided, it was ineffective in preventing a toxic level of salts from accumulating. Much of the plant yard slopes in that direction.

On the southeast-facing side of the property, run-off has penetrated to the fifteenth row of the soybean field. The protection once afforded by the rail spur was lost when the tracks were removed. The circled numbers indicate where photographs were taken. These clearly show the extent of damage to the crop. These will be useful in judging reparations to the farmer. They can also be compared with conditions observed during subsequent cropping years to determine if the damaged areas are healing or spreading.

Photos are always taken along all perimeters of the plant site viewed in both directions. Any unusual conditions are examined closely and carefully described in the written report. The condition of vegetation in roadside ditches is always a clue to run-off or spillage problems.

Container disposal is perhaps one of the most perplexing problems faced by farm center managers. The EPA estimates that in 1986 more than two hundred million pesticide containers, both household and agricultural, were used in the U.S.A. The most prevalent farm chemical containers are the one gallon and the two and a half gallon sizes. Metal cans are usually triple-rinsed and then crushed; after which they can be disposed of as scrap. Plastic containers are frequently burned, but toxic fumes resulting from combustion are a cause for concern. Many areas forbid burning, so these containers can only be disposed of in a hazardous waste dump.

An inquiry to the National AgriChemical Retailers Association revealed that EPA has formed a Container Disposal Task Force and they are drafting environmentally acceptable disposal rules. Meanwhile, a survey has revealed that 46% of farm centers prefer to use mini-bulk reusable containers. However, these one hundred and ten gallon vessels cannot be re-filled with less than fifty-six gallons, according to current EPA rules. Because many farmers need less than fifty-six gallons to treat their fields, the smaller size chemical containers are necessary. Efforts are being put forth by NARA to have EPA allow less than fifty-six gallons in the mini-bulk units.

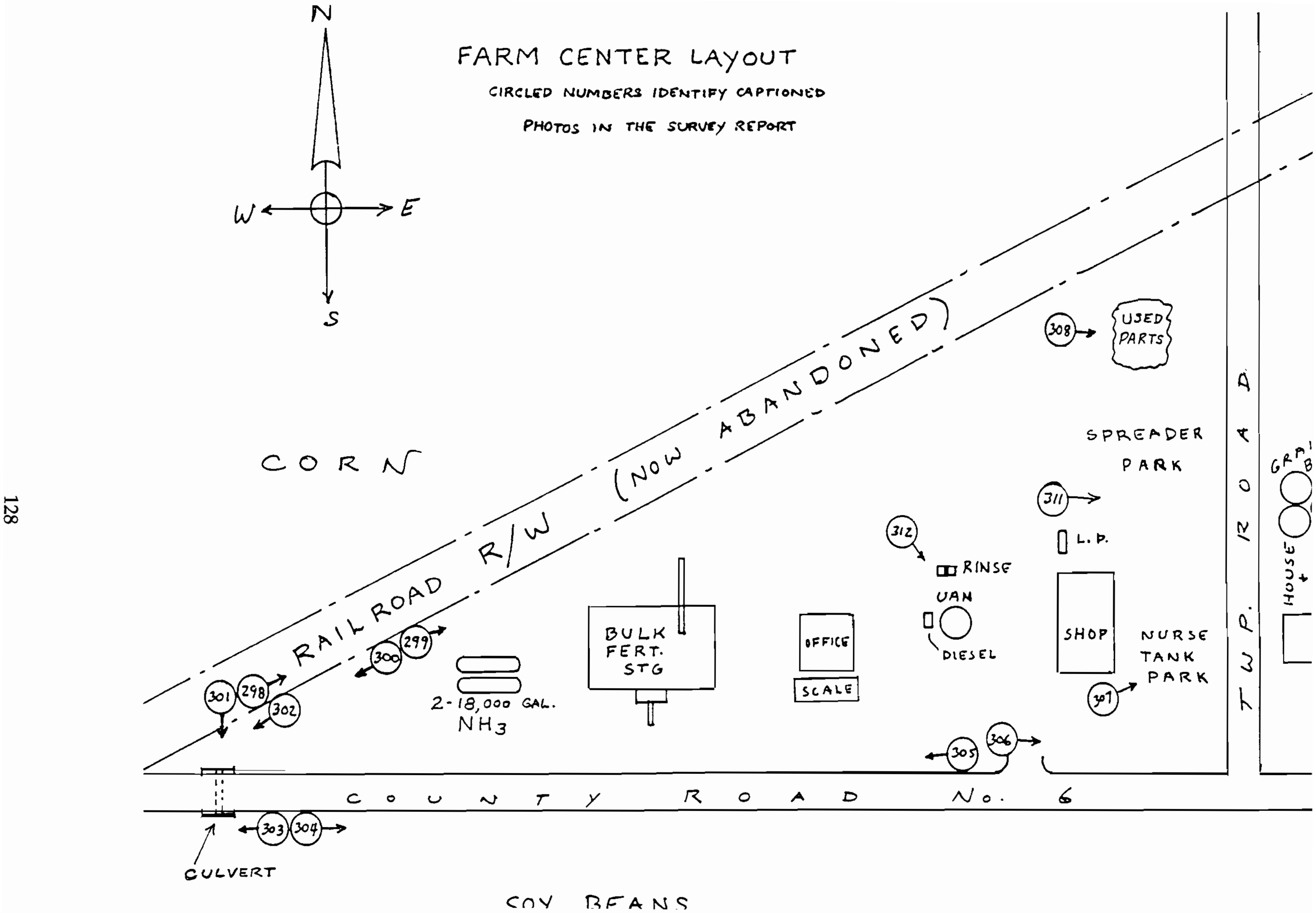
The plant's fuel tanks are also a potential source of a spill. These tanks must be protected from impact damage by substantial guarding. "No Smoking" signs must be posted and the tanks must be clearly labeled for the type of fuel contained, "Diesel" or "Gasoline". Weeds and grass must not be allowed near these tanks.

One final item: if there are drinking water wells on site, or on nearby properties, arrange to have samples of the water checked for evidence of fertilizers or pesticide infiltration. If there is evidence that neighborhood wells could be affected by chemicals from other sources, it may be appropriate to alert the owner to these possibilities. Make sure that wellheads are elevated or curbed to exclude surface run-off. If you use water in making fluid fertilizers, check to ensure that back-syphoning into the well is not possible.

Stewardship is the new buzzword. Be a good steward to your community, your industry, your farmer customers, your employees and keep yourself out of trouble.

In summary, look critically at what MIGHT BE WRONG. Do not leave anything to chance. Defeat Murphy's Law.

One final note: Senator Brock Adams of Washington has recently introduced legislation to protect Puget Sound from disasters as has occurred in Prince William Sound. There are three key provisions: all tankers entering Puget Sound must be double hull vessels. All tankers must have on-board spill control capability. An approved oil spill plan must be in effect on all such vessels. Note the parallel with the environmental protection program recommended for fertilizer plants.

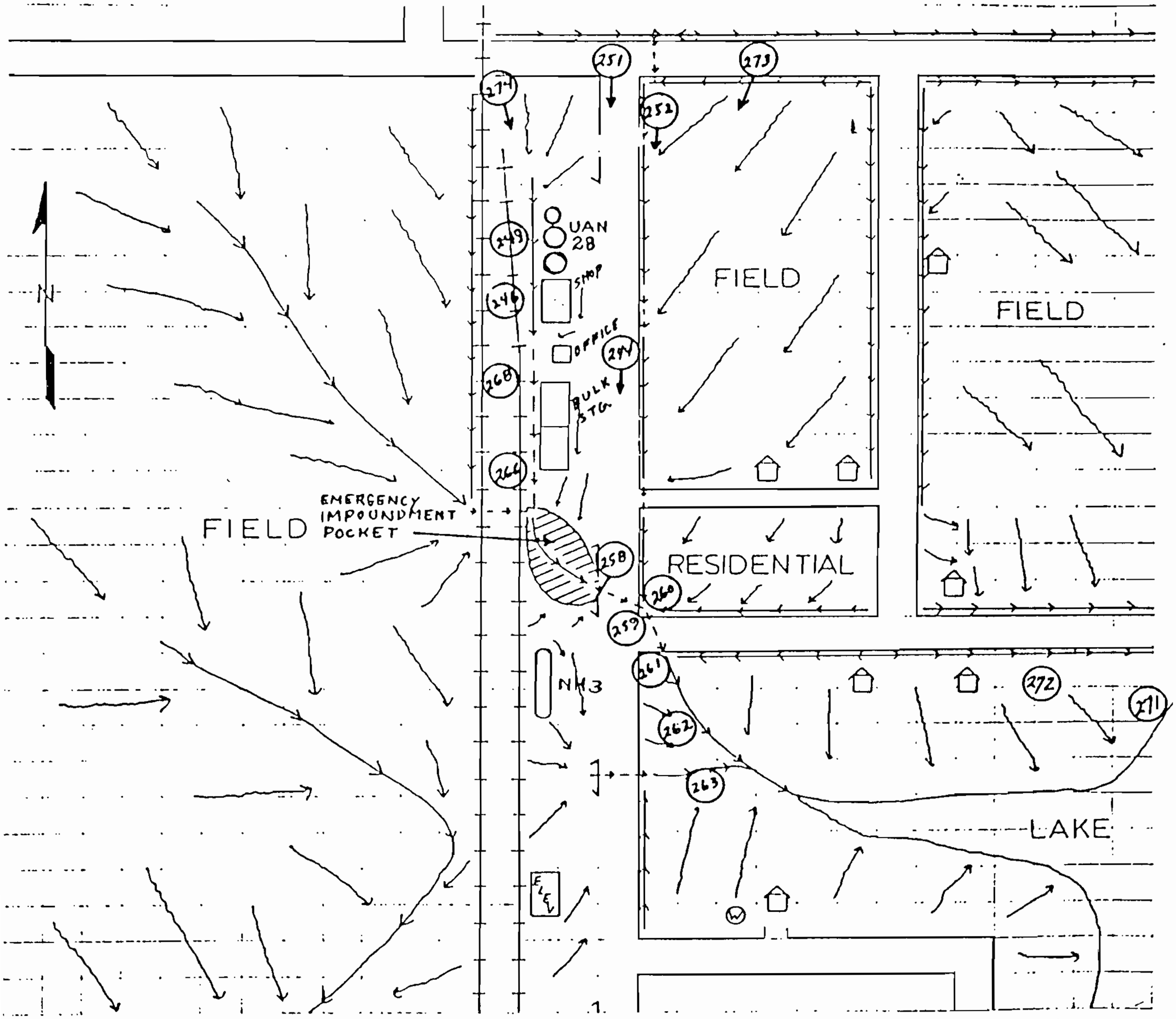

FARM CENTER LAYOUT

CIRCLED NUMBERS IDENTIFY CAPTIONED PHOTOS IN THE SURVEY REPORT

FIGURE 2

# PLANT SITE DRAINAGE AND RUN-OFF

CIRCLED NUMBERS IDENTIFY CAPTIONED PHOTOS IN REPORT



SCALE 1" =200'

IMPOUND AREA - 50,000 GAL.

FIGURE 3

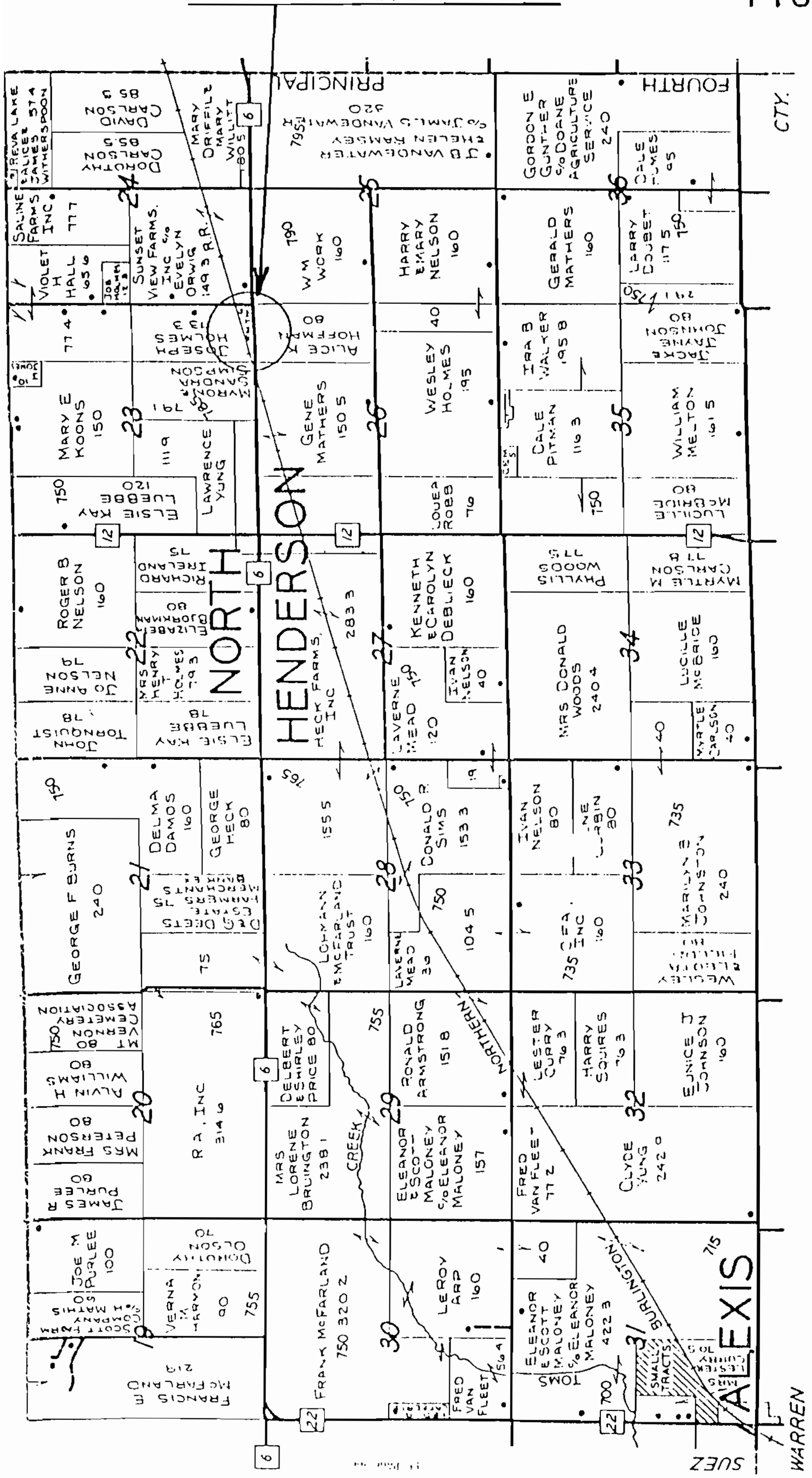
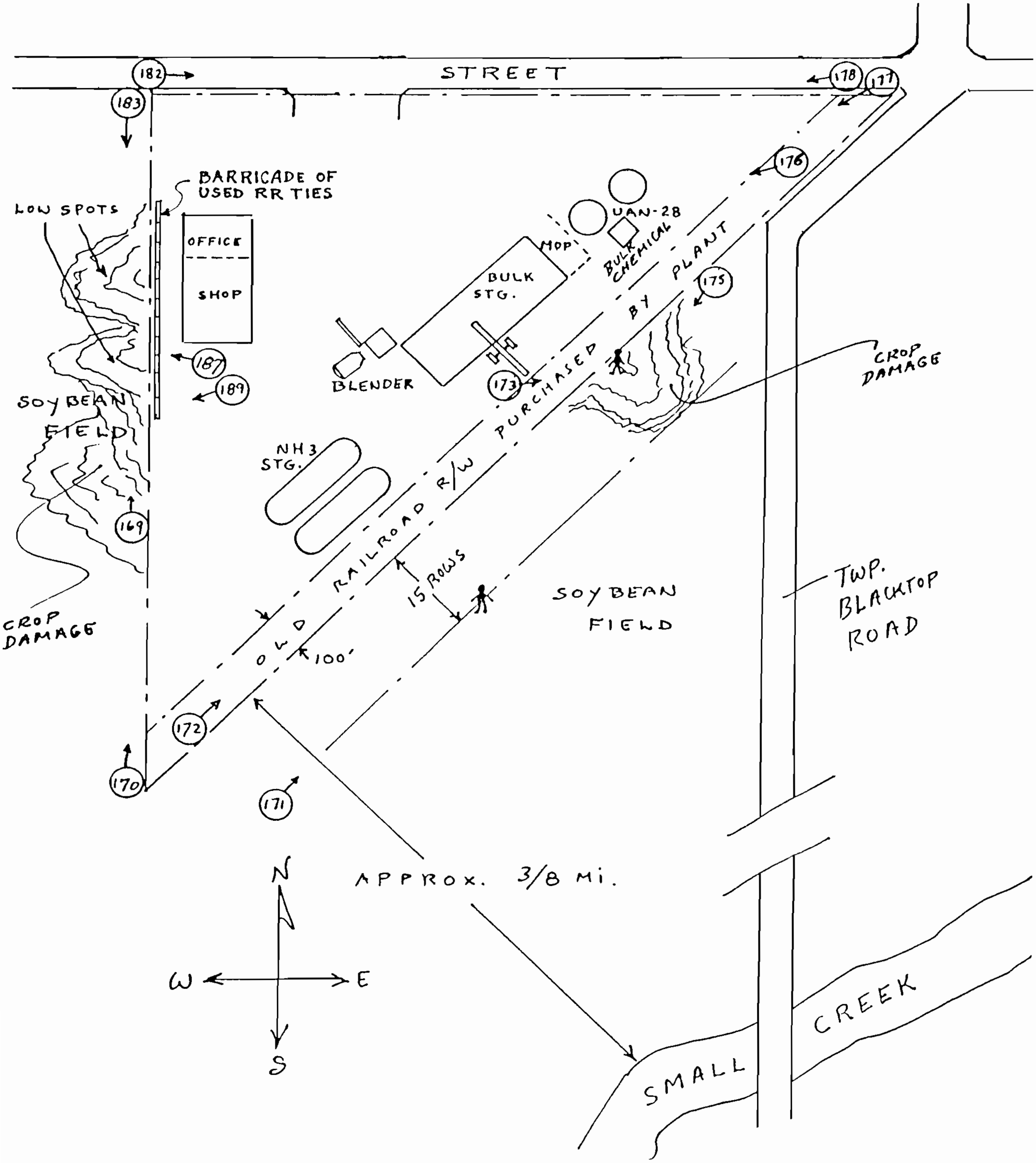

FARM CENTER LOCATION

FIGURE 4

# FARM CENTER LAY-OUT

LOCATIONS WHERE RUN-OFF HAS DAMAGED NEARBY CROPS
CIRCLED NUMBERS IDENTIFY CAPTIONED PHOTOS IN REPORT



# Proper Use of Hydrogeologists

*J.E. McClure, Jr., P.G.*
**GeoTrans, Inc.**

## *INTRODUCTION*

Several preliminary questions must be briefly answered before my main subject can be addressed in its proper context. These questions are:

1. What is a hydrogeologist?, and
2. Why does a member of the Fertilizer Roundtable have to consider using one?

After these points are clarified, the proper use of such creatures can be more easily explored, and a management strategy can be presented.

## *WHAT IS A HYDROGEOLOGIST?*

A person with this title is trained in earth science, and usually is a degreed geologist or engineering geologist. They have specialized however, in the nature and movement of water below the earth's surface. The broad categories of issues that hydrogeologists routinely deal with are:

1. How much water is under a particular site?
2. How much of it can be removed via a well or wells?
3. How did it get there and where did it come from?
4. How fast does it move naturally, or how fast can it be made to move by pumping a well?
5. How is the subsurface water at a site related to the water on the surface?
6. What is the quality and chemistry of groundwater now, in the past, and in the future?
7. Why do groundwater quantity, quality, and flow change, and what can be done to prevent, or induce these changes?

The specific language or argot of hydrogeologists which describes these questions and their subdivisions is much more detailed, specific, and technical than I have presented here, but this list should be kept in mind for perspective' sake by those who utilize these specialists.

The hydrogeologist will use a variety of tools and data inputs to answer the above questions or solve the problems they present. One of the most important of these, at least to the client, but one which can be slighted, or understated in the beginning of a project, is the literature search, or what information is already available about a specific sites groundwater and subsurface conditions.

A good hydrogeologist will know how to find and utilize the work of others which has been previously performed, and he will do so because it is a good scientific method, and it will save field time and expense. The good hydrogeologist will also acknowledge this work by others.

Other tools for collecting new data are:

1. Water level measuring wells, or piezometers;
2. Water quality monitoring wells, which may or may not be the same as the piezometers;
3. Soils and rock information gained during drilling;
4. Aquifer characteristic tests in the field such as pumping or slug tests;
5. Tracer tests for groundwater flow;
6. Borehole logging by resistivity, gamma-ray intensity, or other methods;
7. Aerial photographs in either true or infra red colors, from overflights or satellites;
8. Geophysical measurements, such as ground conductivity, ground resistivity, and magnetometer readings;
9. Groundwater quality measurements for various chemical species, pH, and temperature; and
10. Observations in the field.

Once these new data are collected from whatever kind of tool that is used, they must be analyzed, along with the data collected from previous work. This process of analysis, which may represent 60% of the effort for a particular project, is the process which answers whatever questions are being addressed. To do this analysis, a hydrogeologist will utilize:

1. An orderly array of all available data;
2. Mathematical manipulations;
3. Computer modeling (many, rapid mathematical manipulations!); and
4. Intuition.

Once the analysis is complete, the hydrogeologist will present the client with conclusions, and offer recommendations.

This, then is a hydrogeologist.

## *WHY USE HYDROGEOLOGISTS?*

The need for the services of hydrogeologists by the fertilizer industry is obviously recognized by its members, since my subject is on today's agenda; however, I would like to examine the WHY briefly by an analogy, and in light of recent changes.

In 1979, I was a member of the Kentucky Bureau of Environmental Protection, and was involved to a small extent with, and observed a lot of the initial US EPA assault on what became to be known as the "Valley of the Drums," near Louisville, Kentucky. The origin of these drums of industrial waste was mainly in the various manufacturing plants in the area. There were approximately 17,000 drums at this site, 14,000 of which were empty.

The initial EPA effort, on a budget of $300,000, was designed more for media consumption than remediation, and it worked. Today, 10 years later, we have multi-billion dollar expenditures for starting the cleanup of such sites, joint and several liability, the actual imposition of Ex Post Facto law, and manufacturing in general designated as guilty until proven innocent. This does not deny the fact that many gross abuses were committed, and must be cleaned up or secured, but it also illustrates how quickly public perceptions and priorities can change, and become institutionalized in new directions.

The broad field of agriculture is one with which I am familiar in many of its aspects, having been raised as a county extension agent's son. Particularly, I grew up knowing and observing that agri-business, especially the fertilizer and pesticide manufactures, were the benefactors of farmers, as well as of the world in general.

This feeling was also true of manufacturing in general up until the early 1960s.

I am sure that you are aware that change is occurring in the environmental aspects of agri-business, and that these changes are being brought on by changes in a number of factors. Some of these are:

1. Changing demographics toward urbanization;
2. Increasing economic competition in agriculture, forcing structural changes; and
3. National and world population increases, and the resulting increase in competition for fixed supply resources, such as groundwater.

Examples of recent changes include those of awareness of the importanceof the resource groundwater with respect to agriculture.

In a recent symposium presented by the Association of Groundwater Scientists and Engineers in Baltimore on the 10th and 11th of this month titled "Agricultural Chemicals and Groundwater: An Examination of Important Issues," over 15 studies on this issue were examined, and over 187 additional references concerning the subject were cited. While most of this concern is directed at pesticides, non-point source nitrates were also defiantly pointed out.

Additionally, the State of Wisconsin recently published the results of a survey of grade A dairy farm well water quality which found nitrates above 10 ppm in 7 to 13% of the 534 wells examined. Finally, the American Farm Bureau Federation has distributed the second edition of its "Groundwater and Environmental Pollution Self-Help Checklist for Farmsteads and Farm Fields" (Appendix A), an extremely thorough and well thought out guide, which contains at least 23 questions concerning fertilizer, including whether the farmer has groundwater pollution liability insurance.

Other recent changes have occurred in agricultural practices which affect the relationship between fertilizer application and groundwater. One of these, no-till corn cultivation was studies recently with respect to transport in the unsaturated zone above the water table. Edwards et al., reported in the Journal of Contaminant Hydrology that infiltration of rain fall directly into the ground was 80 times greater than that in tilled plots, which is good for soil conservation, but introduces more nitrates into groundwater if they are applied without regard to this new effect.

This lengthy background discussion of who and why may have covered old ground for you, but it lets me now say that a hydrogeologist is someone who can help you, because you will probably need their help soon.

## *PROPER USE OF HYDROGEOLOGISTS*

A hydrogeologist is a scientist, and will utilize the methods discussed previously to investigate groundwater problems that are presented. The person who uses the services of a hydrogeologist bears the ultimate responsibility of defining the problems.

This is a simple way of stating that a good project, i.e., one that can be efficiently performed and provide definite results, is one that is tightly defined as to goals and objectives, and is controlled while in process. The following steps should be used as a guide by the buyer of hydrogeologic services.

1. Define why the services are needed:
   a. Research on newproducts or processes;
   b. Regulatory requirements for monitoring, such as plant sites;
   c. Assistance in responding to charges of groundwater pollution by regulatory or other bodies; or
   d. Advice in preparation of policies or positions.
2. Meet with the hydrogeologist and discuss the need for services and receive their broad technical input;
3. If the cause for the need for services is well defined, i.e., a regulatory agency or ones own legal staff, and attempt to tighten up the specifications as much as possible. Such points as monitoring well specification, standard practices, evidentiary rules requirements, chain-of-custody, and analytical limits are standard points to be initially defined by the client.

4. Prepare an RFP, or invite a proposal from the hydrogeologist that requires the following steps and approaches:
    a. Presenting an understanding of the problem;
    b. A literature search, and an informal presentation of findings;
    c. A proposed field work plan, with step by step phases of work and their times, with latter steps allowing refinement by preliminary findings;
    d. A plan for any analyses of samples that will be taken, including quality assurance and quality control measures appropriate to the investigation;
    e. Any safety plans that are necessary
    f. A preliminary, informal report of field findings, both initial and any from subsequent modifications in methods, to be presented after or during field work, and which confirms or offers modifications to the original project goals;
    g. One or more draft report of findings, as appropriate to the project, as the analysis of the data is carried out and conclusions and recommendations emerge; and
    h. Submittal of a final report in a format and numbers satisfactory to the client.

As can be seen from this generic project outline, a great deal of interplay takes place between the hydrogeologist and the client. This is *CRUCIAL* to a successful project. Just as crucial is the feedback mechanism that must be built into the fieldwork plan, in order to prevent over-or-under investigating, and getting bad data or wasting money, or both.

Finally, the requirement that plans for the specific parts of the investigation be submitted in advance gives the client a strong control mechanism, and requires the consultant to plan his work (A novel concept to a few in this profession).

This brief paper has attempted to pull together, and present some of the more important points that the Fertilizer Roundtable members should keep in mind when standing in the arena with your cape and sword, waiting for the hydrogeologist to be turned loose.

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Macropores Revisited, A Review by Stuart Cohen of the Journal of Contaminant Hydrology, Vol. 3, p. 115, ff, 1988, Ground Water Monitoring Review, Summer 1989.

# APPENDIX A

## Farm Bureau's Groundwater & Environmental Pollution Self - Help Checklist for Farmsteads and Farm Fields

Purpose: This thought-provoking checklist will help you analyze your own water supply and farming operations.

- ✔ Fill out this Checklist
- ✔ Review it once a year, and
- ✔ Act voluntarily to reduce or prevent pollution from your farming activities.

### 1. BASIC INFO ON YOUR WATER SUPPLY & TESTING, CLIMATE AND SOILS:

Which system provides drinking water for your family and/or livestock?

____ **PUBLIC** (EPA defines it as any system with 15 or more connections or serving 25 or more people. Including most rural water districts.) Water testing and treatment required by federal Safe Drinking Water Act.

____ **PRIVATE** (includes your own system: bottled water; and systems with 14 or fewer connections or systems serving 24 or less people). Water tests generally not required except for dairies and for new wells.

Check ✔ the source/s from which your system draws its water:

**GROUNDWATER**

____ Shallow well, 0 to 50 ft.

____ Medium well, 50 to 150 ft.

____ Well deeper than 150 ft.

____ Artesian well

____ Spring

**SURFACE WATER**

____ Stream

____ River

____ Farm pond

____ Lake

____ Cistern

____ Don't know, but I intend to find out.

Is your water treated to kill bacteria? ____Yes ____ No

If you have a well, is it dug, drilled, or sandpoint? ________

In what year was your well constructed? ____________

Is your well properly grouted to prevent contamination from rainfall and animal contamination from seeping down along the well's casing? ____ Yes ____ No ____ Don't Know

Does your well's casing extend above ground level? (It should.)
____ Yes ____ No

**WATER TESTING**

Have you had your water tested within the last year?
____ Yes ____ No
If No, what year did you last test it?____________

Did the test include any of the following? Check those that apply.

____ pH
____ Nitrate
____ Total Coliform Bacteria
____ Total Dissolved Solids

Done by many state health labs for a small fee. Should be done annually even if no obvious problems exist.

---

____ Pesticide Scan
____ Heavy Metals (lead, arsenic, etc.)
____ Purgable Organic Carbons (fuels, dry cleaning solvents, etc.)

**CLIMATE and SOILS**

What is the average rainfall for your area? ____ inches.
*(Leaching potential increases as annual rainfall increases.)*

Is the bedrock limestone? (Karst Topography)
____ Yes ____ No

Are your topsoils shallow to bedrock (less than 3 ft.)
____ Yes ____ No
*(Thicker top soils may still be a problem depending on soil type.)*

Are your soils generally:
____ Sandy (most likely to allow leaching into groundwater)
____ Loams (medium leaching potential)
____ Clays (least likely to allow leaching)
____ High organic matter (peat or muck)
____ Loam or some combination of those listed above?

How are any ponds or impoundments on your farm recharged?
_____rainfall/runoff
_____groundwater/spring
____ stream
____ pumped well

## II. CHECK YOUR FARM'S POTENTIAL TO POLLUTE GROUND WATER AND YOUR DRINKING WATER SUPPLY

**DO YOU:** **YES* NO**

- Have limestone bedrock fairly close to the surface? .............................. ____ ____
  *(Cracks and sinkholes provide fast movement of runoff and pollutants to groundwater and wells many miles away.)*
- Have sandy soils? ...................... ____ ____
  *(Fertilizers and chemicals can move rapidly to groundwater.)*
- Have water tables within 30 ft. of the surface? ................................ ____ ____
- Have a dug or sandpoint well less than 50 ft deep? ............................... ____ ____
  *(These are generally old, not properly cased or grouted. Easily contaminated by bacteria, rodents and surface runoff.)*
- Have a well pit, uncapped well or abandoned well? ................................ ____ ____
  *(Easily contaminated by surface runoff, flooding and rodents.)*
- Have an older submersible well pump? .... ____ ____
  *(Many older pumps contain lubricating oil with highly toxic PCBs which could contaminate your water supply system.)*
- Have lead water pipes or lead-soldered pipe joints? ............................... ____ ____
  *(Lead is highly poisonous and could leach into drinking water, especially if the water is acidic.).*
- Use your well for both livestock & household use? ................................ ____ ____
  *(Potential for cross contamination exists.)*
- Have livestock.poultry within 200 ft. of a well? ................................ ____ ____
  *(Bacteria, nitrates and disease may reach the well water.)*
- Have a feedlot, manure lagoon or holding facility? ............................ ____ ____
- Have a septic tank/field within 75 ft. of a well (double the distance in sandy soil? ........ ____ ____
  *(Bacteria and nitrate contamination is possible.)*
- Have a surface water drainage well? ...... ____ ____
  *(Runoff moves chemicals & manure directly into groundwater.)*
- Have a farm dump? .................... ____ ____
  *(Improperly disposed house & farm chemicals and animals.)*
- Have an underground fuel tank? .......... ____ ____
  *(Average life of steel tanks is 40 years or less.)*
- Put chemicals or fertilizers into your irrigation system? .......................... ____ ____
  *(Without proper checkvalves and equipment the potentials for backflows into the well exists if the system malfunctions.)*

**DO YOU:** **YES* NO**

- Use chemicals from EPA's Priority Leachers List (see list below)? ........................ ____ ____
  *(If you do use them, try to find a substitute chemical which is equally effective but less likely to leach to groundwater.)*
- Apply sewage sludge? .................. ____ ____
  *(Possible problems with heavy metal buildup, disease and nitrates if not monitored carefully.)*
- Dump or spread used oil to control road crust? ................................ ____ ____
  *(EPA considers this hazardous waste, better recycle it.)*

**IF YOU CHECKED "YES" FOR ONE OR MORE OF THE QUESTIONS ON PAGE 3 AND 4 YOU SHOULD DEFINITELY BEGIN A PROGRAM OF ANNUAL WELL WATER TESTING!**

*Also, if you checked the "YES" column you should try to reduce your system's pollution potential and/or reduce your production costs.

### EPA PRIORITY LEACHERS

*(Current as of October 21, 1987 but could change)*

acifluorfen
alachior
aldicarb
aldicarb sulfone
aldicarb sulfoxide
ametryn
atrazine
atrazine, dealkylated
baygon
bromacil
butylate
carbaryl
carbofuran
carbofuran-30H
carboxin
carboxin sulfoxide
chloramben
alpha-chlordane
gamma-chiordane
chlorothalonil
cyanzine
cycloate
2.4-D
dalapon
dibromochloropropane
DCPA
DCPA acid metabolites
diazinon
dicamba
5-hydroxy dicamba
3.5-dichlorobenzoic acid
1.2 dichloropropane
dieldrin
diphenamid
dinoseb disulfoton
disulfoton sulfone
diuron
endrin
ethylene dibromide
ETU
fenamiphos sulfone
fenamiphos sulfoxide
fluormeturon
heptachlor
heptachlor epoxide
hexachlorobenzene
hexazinone
methomyl
methoxychlor
methyl paraoxon
metolachlor
metribuzin
metribuzin DA
metribuzin DADK
metribuzin DK
nitrates
oxamyl
pentachlorophenol
pichloram
pronamide metabolite.
RH 24.580
propachior
propazine
propham
simazine
2.4.5-T
2.4.5-TP
tebuthiuron
terbacil
trifluralin

## III. OFF-SITE ASSESSMENT

*(i.e., are other people's actions affecting your water supply?)*

What is the approximate distance to the nearest neighbor's well?
(Express in feet or miles)__________.

Is that well:______shallow (less than 50 feet);______deeper than 50 ft?

From a map or by observation. In what direction does the groundwater flow through your property? From the

__________ to the __________. (Check with local Soil Conservation Service or State Geological Survey if you don't know the answer.) Often times groundwater moves toward the nearest creek or river.

Place a check mark ✓ next to all **POLLUTANT SOURCES** within a 1-mile radius of your property where the groundwater seems to be coming from. (If your farm's water supply is surface water you may have to think in terms of many miles upstream.)

| Pollutant Source | Potential Pollution or Problem | If You Suspect/observe these Problems. Request These Tests |
|---|---|---|
| ____ Ag Areas | All problems listed in Part II | TC, NO$_3$, pH, TDS, Pesticide Scan. |
| ____ Wetlands | Polluted recharge water. | Bacteria, NO$_3$. |
| ____ Forests | Pesticide use. | Pesticide scan. |
| ____ Highways | Road salt, lead petroleum. | TDS, chlorides, sodium. |
| ____ Housing | Septic, house and chemicals. | NO$_3$, surfactants, Fecal Coliform & Streptococcus. |
| ____ Fuel Tank | Gasoline, diesel. | Hydrocarbon scan. |
| ____ City | Street runoff, fuels. | TDS, pH, Hydrocarbon scan. |
| ____ Industry | Metals, fuels, solvents. acids. | TDS, pH, Hydrocarbon scan. |
| ____ Food Ind. | Rinse water, cleaning solvents. | Bacteria, TDS, pH, Surfactants. |
| ____ Injection<br>____ Well | Brine, chemicals, & acids. | TDS, pH, acidity, Hydrocarbon Scan, Corrosion Index. |
| ____ Mining | Acid, salts, minerals | TDS, Fe, SO$_4$, pH, Mn, Al, acidity Corrosion Index. |
| ____ Oil & Gas | Brine, sulfur & minerals | TDS, Na, Cl, Ba, Pb, pH, Strontium, Corrosion Index. |
| ____ Golf Club | Pesticide and Fertilizer use. | No$_3$, pH, Pesticide Scan |
| ____ Landfills | Chemicals of all sorts. | TDS, pH, COD. Volatile organics. |
| ____ Sludge | Heavy metals, bacteria. | Bacteria, nitrate, metals. |
| ____ Utilities | Seepage from storage ponds. | TDS, pH |
| ____ Other | | |

TDS = Total Dissolved Solids, TC = Total Coliform Bacteria, NO$_3$ = Nitrates, Al = Aluminum, Fe = Iron, Cl = Chlorides, Mn = Manganese, Ba = Barium, SO$_4$ = Sulfates, COD = Chemical Oxygen DEmand, Pb = Lead, Na = Sodium.

If there is any question in your mind about how any of the pollutant sources you checked above may be affecting your water supply then you should have your water tested. This gives you a baseline against which to compare water test results in future years.

Work closely with local government to deal with off-farm problems.

## IV. FERTILIZER CHECKLIST

| DO YOU: | Yes | No | Can Improve* Investigate | Does Not Apply |
|---|---|---|---|---|
| • Soil test every year, including 2 to 3 feet deep? | ____ | ____ | ____ | ____ |
| *(Deep testing is important in drier climates to determine how much of last year's nitrogen fertilizer remains within the plant's reach.)* | | | | |
| • Have a nutrient "BUDGET" for your cropland? | ____ | ____ | ____ | ____ |
| • Split nitrogen applications by plant growth stages? | ____ | ____ | ____ | ____ |
| • Give fertilizer credits to manure or sewage sludge? | ____ | ____ | ____ | ____ |
| • Give nitrogen credits for previous crops such as alfalfa, soybeans, clover, vetch and other legumes? | ____ | ____ | ____ | ____ |
| • Band fertilizer where possible? | ____ | ____ | ____ | ____ |
| *(Banding reduces the amount of rainfall that contacts the fertilizer as the rainfall percolates down through the soil. Banding also reduces the chances of weeds using the fertilizer before your crop does.)* | | | | |
| • Use goggles and rubber gloves around anhydrous ammonia? | ____ | ____ | ____ | ____ |
| • Reduce use of nitrogen fertilizers in the fall? | ____ | ____ | ____ | ____ |
| *(Spring use increases yield and reduces NO$_3$ leaching.)* | | | | |
| • Use N-inhibitors, such as N-Serve? | ____ | ____ | ____ | ____ |
| • Set "Realistic" yield goals? | ____ | ____ | ____ | ____ |
| *(10 percent higher than the average yield for the last 3 years is reasonable.)* | | | | |

**Even if you checked the YES or the NO column you also should check the "Can Improve" If you think there's the slightest chance you could reduce your system's pollution potential and/or your production costs.*

## V. STORAGE OF AG CHEMICALS

| DO YOU: | Yes | No | Can Improve* Investigate | Does Not Apply |
|---|---|---|---|---|
| • Know whether your fire department would let a building burn if it contained ag chemicals, rather than risk having their water carry chemicals to groundwater or nearby streams? | ____ | ____ | ____ | ____ |
| • Padlock chemical storage areas? | ____ | ____ | ____ | ____ |
| • Keep duplicate records of amounts and types of chemicals in storage and keep one set someplace else other then your chemical storage building? | ____ | ____ | ____ | ____ |
| *(The extra record is useful in case of fire.)* | | | | |
| • Know which chemicals must be stored in a heated area to prevent loss of effectiveness due to freezing? | ____ | ____ | ____ | ____ |
| • Have any chemical containers with missing or unreadable labels? | ____ | ____ | ____ | ____ |

## VI. HANDLING & APPLICATION OF AG CHEMICALS

| DO YOU: | | | | |
|---|---|---|---|---|
| • Know that different parts of your body absorb pesticides at different rates? | ____ | ____ | ____ | ____ |

| Anatomy | % Parathion Absorption |
|---|---|
| scalp | 32.1 |
| ear canal | 46.5 |
| forehead | 36.3 |
| forearm | 8.6 |
| palm | 11.8 |
| abdomen | 18.4 |
| scrotum | 100.0 |
| ball of foot | 13.5 |

**(Researchers in California measured the percent absorption of parathion by different parts of the anatomy:) Most other pesticides have not been checked for body absorption rate.**

| DO YOU: | Yes | No | Can Improve* Investigate | Does Not Apply |
|---|---|---|---|---|
| Know that symptoms of low-level organophosphate insecticide poisoning closely mimic the symptoms of exhaustion or flu?<br>*(Symptoms include headaches, loss of appetite, nausea, dizziness, weakness and sweating.)* | | | | |
| Know that a product with higher water solubility, longer persistence, and low soil absorption has a greater potential of reaching groundwater? | | | | |
| Use integrated Pest Management (IPM) to determine whether the $ loss to the pest is great enough to warrant spraying, rather than spraying by schedule? | | | | |
| Use one of five specifically defined types of conservation tillage (reduced till, mulch till, slot till, ridge till, or no-till?<br>*(They reduce the amount of soil, chemicals & fertilizer that is eroded to surface waters.)* | | | | |
| Band herbicides, insecticides, and other chemicals, rather than broadcasting them, to cut your costs and reduce their potential for pollution? | | | | |
| Read the label before applying any chemical, and follow it? | | | | |
| Calibrate spray nozzles before use? | | | | |
| Know about electrostatic sprayers?<br>*(Greater % of spray stays on crop.)* | | | | |
| Mix and load chemicals and fertilizers at least 100 feet away from your well?<br>*(The closer you are, the easier it is for spilled chemicals to get into well.)* | | | | |
| Use rubber gloves and boots when handling chemicals? | | | | |
| *(Leather absorbs chemicals and keeps it in contact with your skin for days?* | | | | |
| Measure concentrates and dilutions accurately before adding to tank? | | | | |
| Drain the container into the spray tank by holding it in the vertical position for 30 seconds? | | | | |
| Triple rinse containers as soon as they are emptied before the residue dries? | | | | |
| Empty rinsate into your spray tank? | | | | |
| Have an air gap between the water supply hose and the top of your spray tank to prevent back-siphoning? | | | | |
| Have check valve and proper safety equipment on irrigation wells? | | | | |

> **Even if you checked the YES or the NO column you also should check the "Can Improve" If you think there's the slightest chance you could reduce your system's pollution potential and/or your production costs.*

| DO YOU: | Yes | No | Can Improve* Investigate | Does Not Apply |
|---|---|---|---|---|
| Pump tailwater pits often and reuse the water for irrigation to prevent chemical residue from leaching into groundwater? | | | | |
| Use irrigation scheduling?<br>*(If soil is at field capacity, excess water and chemicals will likely move down past root zone.)* | | | | |
| Delay application to prevent washoff or surface runoff if heavy rain is forecast? | | | | |
| Drive tractor into wind or at right angles to the wind whenever possible when spraying to prevent drift from getting on you? | | | | |
| Refrain from draining rinse water from equipment near or into ditches, streams, ponds, lakes or other water sources?<br>*(Rinse water containing any quantity of certain pesticides are classified as hazardous wastes according to state and federal laws.)* | | | | |
| Wear one of the new types of disposable coveralls when mixing or applying chemicals?<br>*(It's not very expensive and they do a good job of protecting you.)* | | | | |
| Use Extension Service recommendations for washing spray clothes? | | | | |
| Use crop rotation to avoid buildup of pest populations and maintain or improve soil conditions? | | | | |
| Alternate pest control products and use crop varieties that are pest resistent? | | | | |
| Have general groundwater pollution liability insurance? | | | | |
| KEEP COMPLETE APPLICATION RECORDS<br>*(i.e. which chemical, how much, application rate, date, time, temperature, wind conditions, which field, and reason for spraying.)* | | | | |

## VII. CONTAINER DISPOSAL

| DO YOU: | Yes | No | Can Improve* Investigate | Does Not Apply |
|---|---|---|---|---|
| Return unopened chemicals for a refund? | | | | |
| Check the product label for specific container disposal instructions from the manufacturer? | | | | |
| Triple rinse and puncture metal pesticide containers and recycle or dispose of them in approved landfills? | | | | |
| Follow local and state laws on disposal of plastic and paper pesticide containers? | | | | |
| Live in an area that sponsors voluntary container collection programs?<br>*(if not, you might want to help start one.)* | | | | |
| Burn plastic, paper, and other combustible materials after each day's use per application site? | | | | |

| DO YOU: | Yes | No | Can Improve* Investigate | Does Not Apply |
|---|---|---|---|---|
| • Burn only in daylight hours and have one person responsible to be in attendance for the entire period of the burn? . . . . . . . . . . . . . . . . | | | | |
| • Dispose of used motor oil at recycling centers? . . . . . . . . . . . . . . . . . . . . . . . . . . . . | | | | |

> *Even if you checked the YES or the NO column you also should check the "Can Improve" If you think there's the slightest chance you could reduce your system's pollution potential and/or your production costs.*

### VIII. HOW TO TAKE A WATER SAMPLE

Always contact the lab where you plan to have the water tested, and ask them for sampling methods, containers, and packaging and delivery instructions.

Your method and timing of taking a sample will vary slightly depending on which point in the system you are concerned about:

1. Actual quality of the main source of water, (groundwater, stream, river, or main distribution lines of a public water system.) Remove the faucet's aerator, sterilize the faucet opening by flaming and let the water run for 10 minutes before taking the sample.
2. Condition of your water pipes or storage tanks. Remove the aerator from your faucet, sterilize the faucet opening with flame, and take the sample within 3 or 4 seconds after you turn the water on.

TYPE OF SAMPLING CONTAINER. For some tests, water samples can be submitted in a plastic bag or bottle. Other tests require special dark-colored glass bottles. ASK THE LAB!

TIMELINESS. Usually, it's best to test the sample as soon as possible. Labs should receive within 24 hours (48 hours at the latest).

### HANDLING OF SAMPLE CONTAINERS:

- Do not touch the inside of the container or inside of the lid.
- Refrigerate or pack in ice and deliver to lab as quickly as possible if lab so instructs. (Don't throw the sample in the back seat and run all your errands before you stop at the lab.)
- Don't pump gasoline before taking the sample; ethylene dibromide (EDB) in the gasoline will evaporate off your hands into the sample.

For most accurate results, water samples should always be collected by a disinterested third party trained in proper sample collection procedures, and samples should be tested at an Environmental Protection Agency certified laboratory.

### IX. RECOMMENDED INDIVIDUAL ACTIONS

1. Even if no obvious water problems exists, household water supplies should **be tested ANNUALLY** by your county or state Health Department for: pH, nitrates, total coliform bacteria, and dissolved solids. Testing water for every containment is possible, but very expensive and not necessary. **It is more important to test on a regular basis for a few indicators of contamination and to maintain a record of water quality.** This helps to identify changes in the supply, contamination of the water source or deterioration of the water system. However, if you suspect other contaminants, test for them too.
2. Test livestock and poultry water supplies ANNUALLY for pH, total dissolved solids, sulfate, flouride, calcium, magnesium, iron, copper, arsenic, cadmium, lead, nitrate, barium, total coliform, fecal coliform bacteria, and total plate count.
3. Review this Checklist at the end of each calendar year and jot down which potential problem areas you improved on, and which ones you can work on in the coming year.

**Record of Household Water Tests**

| Year | Date | pH 6.8 to 7.5* | Nitrates $NO_3$-N 10ppm* | Total Coliform Bacteria 0/100ml* | Total Dissolved Solids 500ppm* | Other |
|---|---|---|---|---|---|---|
| 1987 | | | | | | |
| 1988 | | | | | | |
| 1989 | | | | | | |
| 1990 | | | | | | |
| 1991 | | | | | | |
| 1992 | | | | | | |
| 1993 | | | | | | |
| 1994 | | | | | | |
| 1995 | | | | | | |
| 1996 | | | | | | |
| 1997 | | | | | | |
| 1998 | | | | | | |
| 1999 | | | | | | |
| 2000 | | | | | | |

### X. SUGGESTED LOCAL FARM BUREAU ACTIVITIES

- Help see that as many farmers as possible get to use this checklist at various meetings. At these meetings, always try to bring in a local water quality expert to make a presentation and answer questions.
- As an educational service, set up a booth at a county fair or a farm show or field day and test water samples for nitrates. (Pennsylvania Farmers Association (PFA) tested over 1,000 samples that farmers brought into PFA's booth at Ag Progress Days. Cost was only 20 cents/test.)
- Hold a county-wide Safe Drinking Water Clinic in cooperation with Extension Service, county Health Department, local well driller, and local water conditioning and testing companies. Pennsylvania Extension Service has an excellent model for this activity. (Your state Farm Bureau NER Coordinator can get more information about it from AFBF.)

If you have any questions or want more information, call your:

- **County Extension Agent**
- **Soil Conservation Service**
- **Local Water Testing Lab**
- **Regional U.S. EPA Office**
- **State Dept. of Agriculture**
- **State Health Dept.**
- **State Environment Agency**

## FOR FURTHER READING:

Contact your state or county Farm Bureau office and request the publication: "Protecting our Groundwater. a Grower's Guide".

**BACKGROUND:** This checklist was developed as a result of a recommendation by the American Farm Bureau Federation's Special Study Committee on Environmental Pollution.

The committee report stated:

> Physical conditions affecting the vulnerability of groundwater to agricultural chemical contamination involve depth to the water table, recharge characteristics, aquifer media, soil types, topography, impact of unsaturated zone, and the conductivity of the unsaturated zone. All these discussions pointed to the "site specific" nature of the resource considerations. . .
>
> Information on farm management practices that will reduce the potential for movement of agricultural chemicals downward into the groundwater is needed at the user level. . . There is also a need to promote increased understanding of practices that will improve nutrient management and minimize nitrogen losses to the environment.
>
> As part of the effort to educate farmers on the safe, responsible practices in agricultural chemical use and environmental concerns, there could be made available through states an Environmental Audit Program for self-examination by individual farmers.
>
> The questionaire/checklist type program would be designed to highlight the basic safe environmental checkpoints on the farm, for example safe storage and handling of agricultural chemicals, mixing and loading locations and techniques.

*The Committee recommended that the self-help program be developed by AFBF "for dissemination to State Farm Bureaus for use at the County level by individual farmers."*

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# Methods For Optimizing the Design of Monitoring Well Systems

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## INTRODUCTION

Investigation of groundwater contamination is expensive, due in large part to the high cost of direct methods of subsurface data acquisition such as drilling, monitoring well installation, sampling, and chemical analyses. Indirect methods facilitate interpretation of subsurface conditions based on surficial measurements (using soil gas analysis or surface geophysical surveys, for example) or based on surface conditions (using photointerpretation, for example). Subsurface data acquired indirectly is generally less costly, but also less definitive, than data acquired directly. As a result, monitoring wells are usually needed to confirm interpretations derived using indirect methods.

The objectives and uses of monitoring wells are varied (Table 1). Factors that affect that number of wells needed to achieve study goals are listed in Tables 2 and 3. Selective application of indirect data collection tools to optimize and augment monitoring well system design can result in significant cost savings. The purpose of this paper is to present an overview of remote investigatory methods that can be used to optimize the design of monitoring well systems. Methods considered include: historic air photo interpretation, fracture trace analysis, soil gas analysis, surface geophysical surveys, and simulation analysis.

## HISTORIC AERIAL PHOTOGRAPH INTERPRETATION

Government agencies have made extensive use of aerial photographs since the 1930s for the study of natural resources (Stoner and Baumgardner, 1979). For example, the U.S. Soil Conservation Service uses photos for soil mapping; the U.S. Department of Agriculture analyzes photos to check farmer compliance with government programs; and the U.S. Geological Survey uses photos to map and interpret geologic conditions. During waste site investigations, the U.S. Environmental Protection Agency and others analyze historic aerial photographs to document disposal practices and locations, drainage patterns, signs of vegetative stress, and other factors relevant to assessing subsurface chemical migration (Phillipson and Sangrey, 1977). Much of the photo-interpretative work involves qualitative stereoscopic analysis of a series of historic aerial photographs available for a particular site.

Conventional aerial photography has been produced on behalf of government agencies for the entire United States. Much of the photography is vertical black and white coverage of moderate scale, typically about 1:20,000. Aerial photographs and remote sensing images are available through several agencies (Table 4). In particular, the National Cartographic Information Center (NCIC) in Reston, Virginia, catalogs and disseminates information about aerial photographs and imagery available from public and private sources. NCIC will provide a listing of available aerial photographs for any location in the United States and order forms. Historic aerial photographs taken every few years are available for many parts of the country.

## FRACTURE TRACE ANALYSIS

Fracture trace analysis involves stereoscopic study of aerial photographs to identify surface expressions of vertical or nearly vertical subsurface zones of fracture concentration (Figure 1). In fractured rock terrain, particularly in karst areas, groundwater flow and chemical transport are usually concentrated in fractures.

Lattman (1958) defined a photogeologic fracture trace as "a natural linear feature consisting of topographic (including straight stream segments), vegetation, or soil tonal alignments, visible primarily on aerial photographs, and expressed continuously for less than one mile . . . (that are not) related to outcrop pattern of tilted beds, lineation and foliation, and stratigraphic contacts." A lineament is a similar feature that is expressed for more than one mile. Numerous papers published in the 1960s and 1970s document the application of fracture trace analysis to hydrogeologic investigation (Lattman and Parizek, 1964; Siddiqui and Parizek, 1971; Parizek, 1976; Sharpe and Parizek, 1979; and Parizek, 1987, for example). A manual on the principles and techniques of fracture trace analysis was prepared by Meiser and Earl (1982).

Fracture trace analysis is widely used to site productive water supply wells and to guide the placement of monitoring wells at contamination sites. The significance of preferential groundwater flow along fracture zones for monitoring chemical migration is illustrated in Figure 2. Extensive chemical migration may go undetected if monitoring wells are located in low permeability rock between fracture zones. A case study involving the use of fracture trace analysis to define and remediate TCE contamination in fractured bedrock was described by Schuller et al. (1982).

## *SOIL GAS ANALYSIS*

Soil gas surveys have become increasingly popular during the 1980s to provide cost-effective preliminary information regarding the location, extent, and composition of volatile organic compounds (VOCs) in soil and groundwater. In a typical survey, soil gas is extracted from a thin probe driven three to six feet below ground (Figure 3) and then analyzed for specific compounds using gas chromatography. Analytical data derived from soil gas studies are used to design monitoring well networks, locate tank or pipeline leaks, and define contaminant plumes. Methods, limitations, and applications of soil gas surveying have recently been described by Marrin and Kerfoot (1988), Marrin (1988), Kerfoot (1988), Silka (1988), and Thompson and Marrin (1987) among many.

Application and interpretation of soil gas surveys are dependent on understanding the physics of soil gas migration as influenced by subsurface conditions. Ideally, compounds such as VOCs monitored using soil gas analysis will: (1) be subject to little retardation in groundwater; (2) partition significantly from water to soil gas (i.e. have a high Henry's constant); (3) have sufficient vapor pressure to diffuse significantly upward in the unsaturated zone; (4) be persistent; and (5) be susceptible to detection and quantitation by affordable analytical techniques. Soil gas surveys are most applicable to dry, coarse-grained soils with low organic carbon content and a water table below ten to fifteen feet.

Subsurface heterogeneities can confound data interpretation. For example, false negative interpretations may be due to the presence of gas barriers (perched groundwater, clay lenses, or irrigated soils) or compound properties. False positive interpretations may result from interferences posed by surficial spills, shallow sewers or natural gas lines. Correlation of VOC concentration contours in soil gas and groundwater is limited by all of these factors.

At many sites, soil gas surveys are utilized to provide a preliminary delineation of VOC migration in a quick, non-disruptive, and cost-effective manner (Figure 4). This information is typically used to limit the number and optimize the locations of monitoring wells.

## *SURFACE GEOPHYSICS*

A variety of surface geophysical instruments are available for indirectly defining the extent of subsurface contamination, presence of buried objects (such as drums, tanks, pipelines), and stratigraphy (Zohdy et al., 1974; and Benson et al., 1982). These instruments operate by measuring physical properties of the subsurface such as resistivity, electrical conductivity, dielectric constant, and temperature. Interpretation of subsurface conditions depends on measurement of changes in these properties that are affected by the interpreted condition.

A brief summary of surface geophysical methods and their application is provided in Table 5. Guidance on the use of surface geophysical survey techniques and case histories are given by Grady and Haeni (1984), Greenhouse and Monier-Williams (19B5), McNeill (1980a, 1980b, 1980c), Slaine and Greenhouse (1982), Rumbaugh et al. (1987), and Ladwig (1982).

## *NUMERICAL SIMULATION*

Insight to complex subsurface problems can be gained by simulation analysis. Modeling provides a means of synthesizing available data and assessing the significance of uncertainty associated with incomplete site characterization. As a result, modeling can be used in subsurface contamination investigations for many purposes including design of monitoring wells and monitoring well systems, analysis of groundwater flow and chemical transport pathways and rates, prioritizing field data acquisition needs, analysis of alternative remedial measures, etc. Applications of models in groundwater investigations are widely described (NWWA, 1987, and Cohen, 1987, for example). Modeling to optimize monitoring well system design may or may not be cost effective, depending on the complexity of the problem being evaluated (i.e. whether a model is needed or simpler data analysis will suffice) and the expertise of the modeler.

## *CONCLUSIONS*

Experience has demonstrated that characterization of subsurface chemical migration can be complex and costly. To maximize cost effectiveness, remedial investigations should be conducted in phases whereby preliminary results can be used to guide later study. Significant cost savings can be realized by the selective use of indirect investigatory techniques to optimize the design of a groundwater monitoring system.

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### TABLE 1.
### Objectives and Uses of Monitoring Wells

- Define geologic conditions
  - + drilling and logging
  - + borehole geophysics
- Determine groundwater flow directions and rates
  - + water-level surveys
  - + hydraulic tests
  - + borehole flowmeter surveys
  - + tracer tests
- Delineate the nature and extent of contamination
  - + sampling and chemical analysis
- Define chemical migration pathways
  - + data synthesis/analysis
- Facilitate design of a remedy
  - + data synthesis/analysis
- Evaluate the effectiveness of remediation
  - + sampling and chemical analysis
  - + water-level surveys

### TABLE 2.
### Factors Favoring the Need for More Monitoring Wells.

- Stratigraphic heterogeneity (spatial variation of hydraulic properties, fracture zones, etc. )
- Manmade heterogeneities (utility lines, pipelines, basements, etc.)
- Complex structural geology
- Multiple flow zones/layers
- Complex and multiple chemical sources
- Complex chemistry (NAPL sinkers and floaters, variable attenuation, etc.)
- Extensive chemical migration
- Multiple and changing flow directions
- Low dispersion potential

### TABLE 3.
### Factors Favoring the Need for Fewer Wells

- Simple hydrogeologic conditions
- Little chemical migration
- High dispersion potential (detection monitoring)

### TABLE 4.
### Sources of Aerial Photographs and Related Information

National Cartographic Information Center
USGS National Center
Reston, Virginia 22092

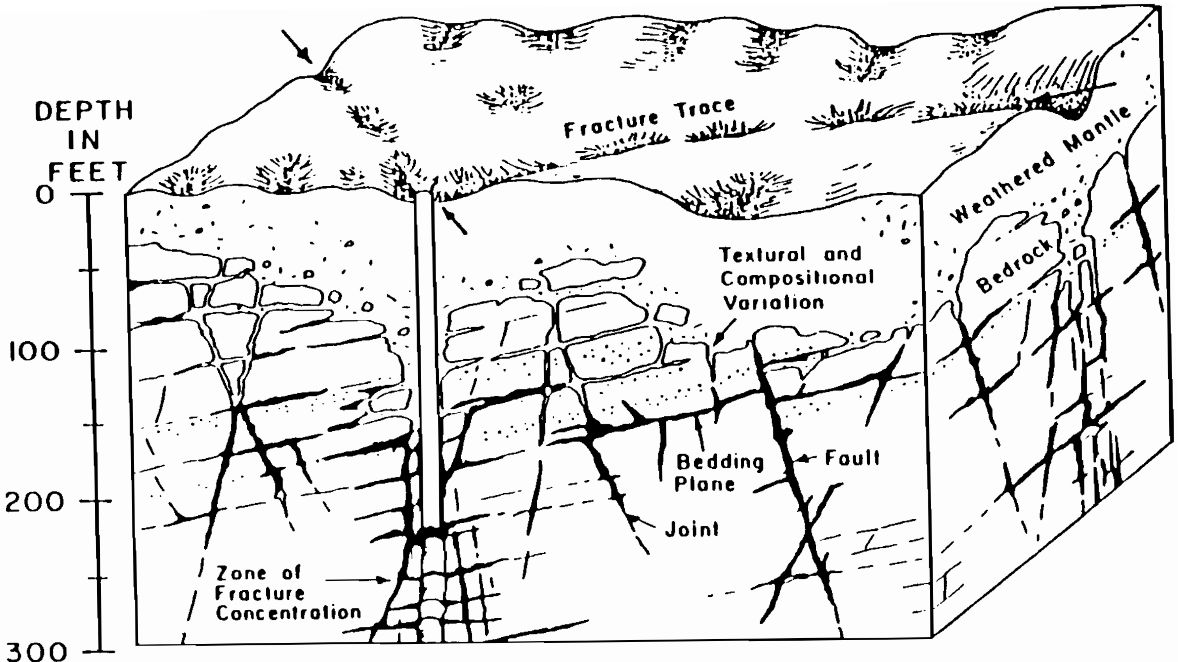
U.S. Department of the Interior
Geological Survey
EROS Data Center
Sioux Falls, South Dakota 57198

Western Aerial Photograph Laboratory
Administrative Services Division
ASCS-USDA
2505 Parley's Way
Salt Lake City, Utah 84109

The National Climatic Center
National Oceanic and Atmospheric Administration
Federal Building
Asheville, North Carolina 28801

**TABLE 5.**
**Summary of Surface Geophysical Methods (modified after O'Brien and Gere, 1988).**

| Surface Geophysical Survey Method | Applications | Advantages | Limitations |
|---|---|---|---|
| SEISMIC REFRACTION AND REFLECTION<br>Determines (lithological changes in the subsurface. | Groundwater resource evaluations<br>Geotechnical profiling.<br>Subsurface stratigraphic profiling including top of bedrock. | Relatively easy accessibility.<br>High depth of penetration dependent on source of vibration.<br>Rapid areal coverage. | Resolution can be obscured in layered sequences.<br>Susceptibility to noise from urban development.<br>Difficult penetration in cold weather (depending on instrumentation).<br>Operation restricted during wet weather. |
| ELECTRICAL RESISTIVITY<br>Delineates subsurface resistivity contrasts due to lithology, groundwater, and changes in groundwater quality. | Depth to water table estimates.<br>Subsurface stratigraphic profiling.<br>Groundwater resource evaluations.<br>High ionic strength contaminated groundwater studies. | Rapid areal coverage.<br>High depth of penetration possible (400-800 ft.)<br>High mobility.<br>Results can be approximated in the field. | Susceptibility to natural and artificial electrical interference.<br>Limited use in wet weather.<br>Limited utility in urban areas.<br>Interpretation that assumes a layered subsurface.<br>Lateral heterogeneity not easily accounted for. |
| ELECTROMAGNETIC CONDUCTIVITY<br>Delineates subsurface conductivity contrasts due to changes in groundwater quality and lithology. | Subsurface stratigraphic profiling.<br>Groundwater contamination studies.<br>Landfill studies.<br>Groundwater resource evaluations.<br>Locating buried utilities, tanks, and drums. | High mobility.<br>Rapid resolution and data interpretation.<br>High accessibility.<br>Effectiveness in analysis of very high resistivity.<br>Equipment readily accessible. | Data reduction less refined than with resistivity.<br>Use unsuitable in areas with surface or subsurface power sources, pipelines, utilities.<br>Less vertical resolution than with other methods.<br>Limited use in wet weather. |
| GROUND PENETRATING RADAR<br>Provides continuous visual profile of shallow subsurface objects, structure, and lithology. | Locating buried objects.<br>Delineation of bedrock subsurface and structure.<br>Delineation of karst features.<br>Delineation of physical integrity of manmade earthen structures. | Great areal coverage.<br>High vertical resolution in suitable terrain.<br>Visual picture of data. | Limited depth of penetration.<br>Accessibility limited due to bulkiness of equipment and nature of survey.<br>Interpretation of data qualitative.<br>Limited use in wet weather. |
| MAGNETICS<br>Detects presence of buried metallic objects. | Location of buried ferrous objects.<br>Detection of boundaries of landfills containing ferrous objects.<br>Location of ironbearing rock strata and dikes. | High mobility.<br>Data resolution possible in field.<br>Rapid areal coverage. | Detection dependent on size and ferrous content of buried object.<br>Difficult data resolution in urban areas.<br>Limited use in wet weather.<br>Data interpretation complicated in areas of natural magnetic drift. |



(After Lattman and Parizek 1964)

Figure 1. Relationship between surface fracture traces and zones of subsurface fracture concentration.

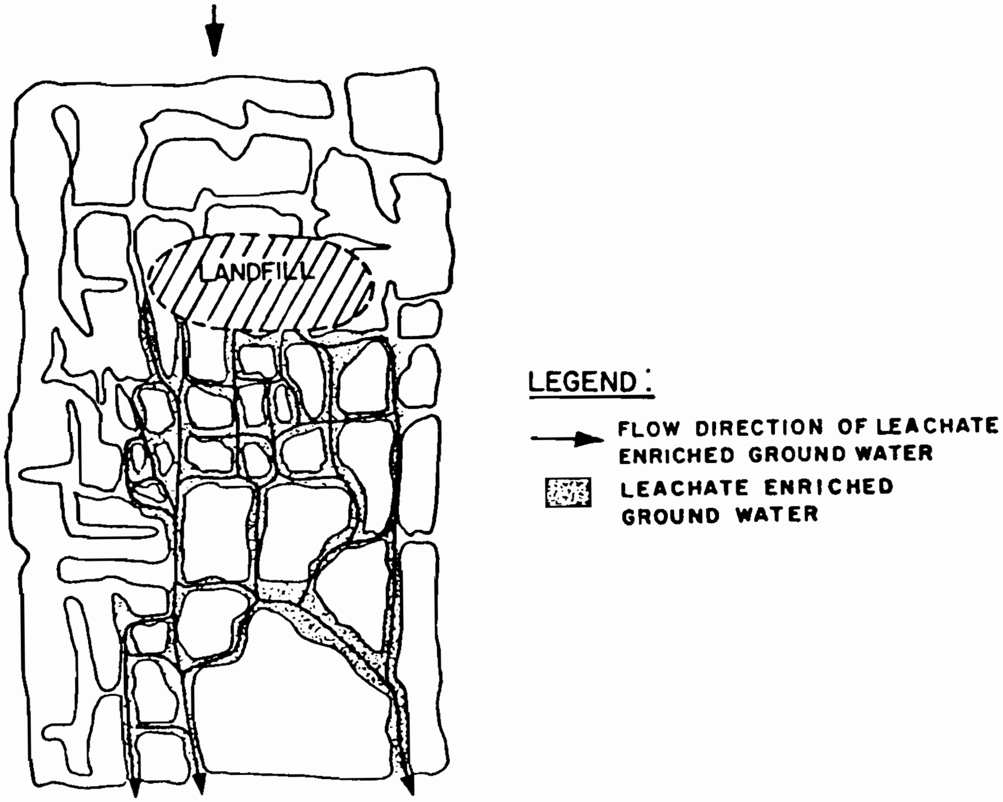
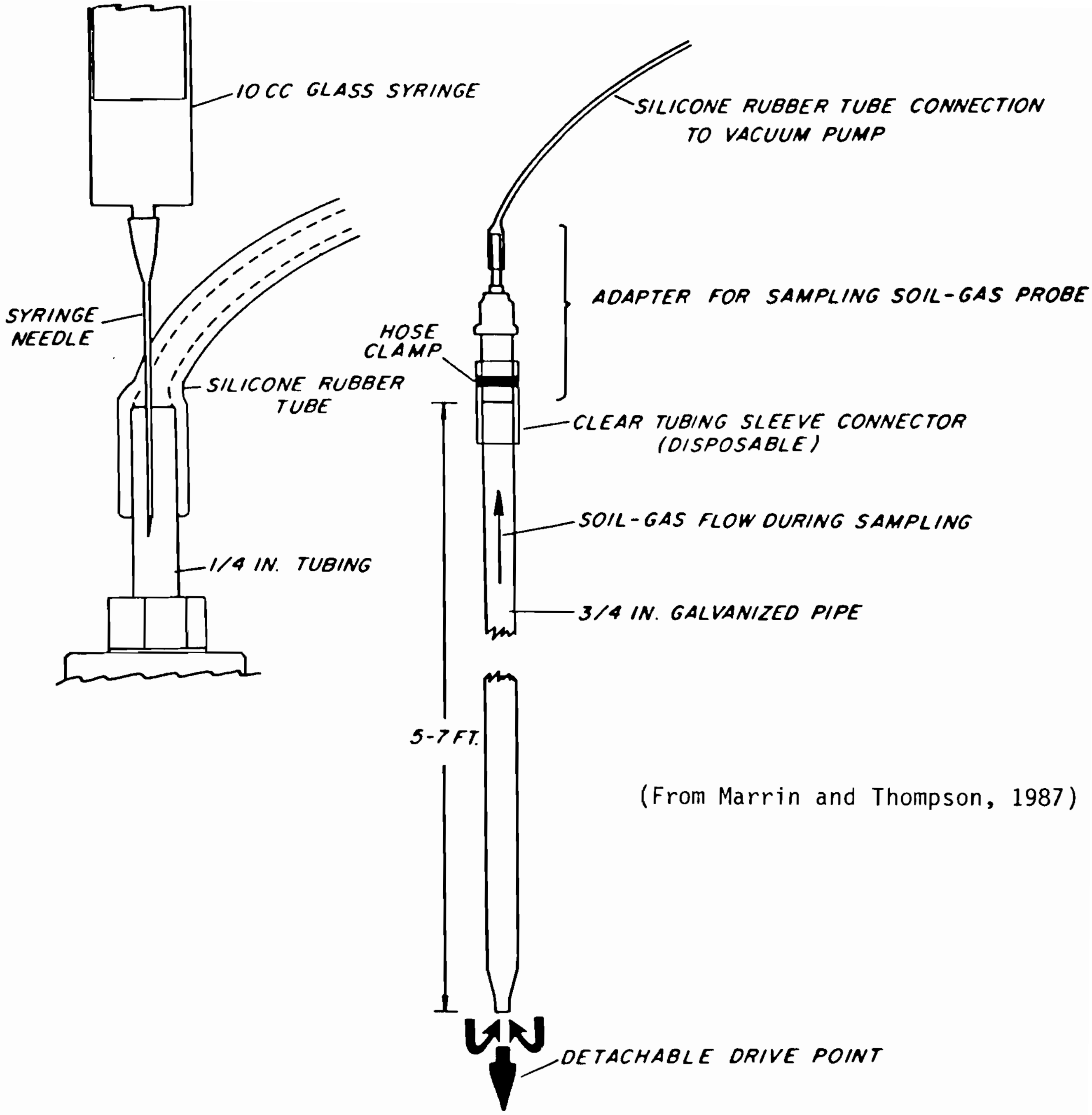


Figure 2. Schematic plan view of preferential groundwater flow and chemical migration via fracture zones from a landfill (from USEPA, 1980). Depending on monitoring well location, migration may or may not be detected.



(From Marrin and Thompson, 1987)

Figure 3. Typical soil gas sampling device showing syringe needle sampling through soil gas evacuation line and soil gas probe evacuation set-up (from Marrin and Thompson, 1987).

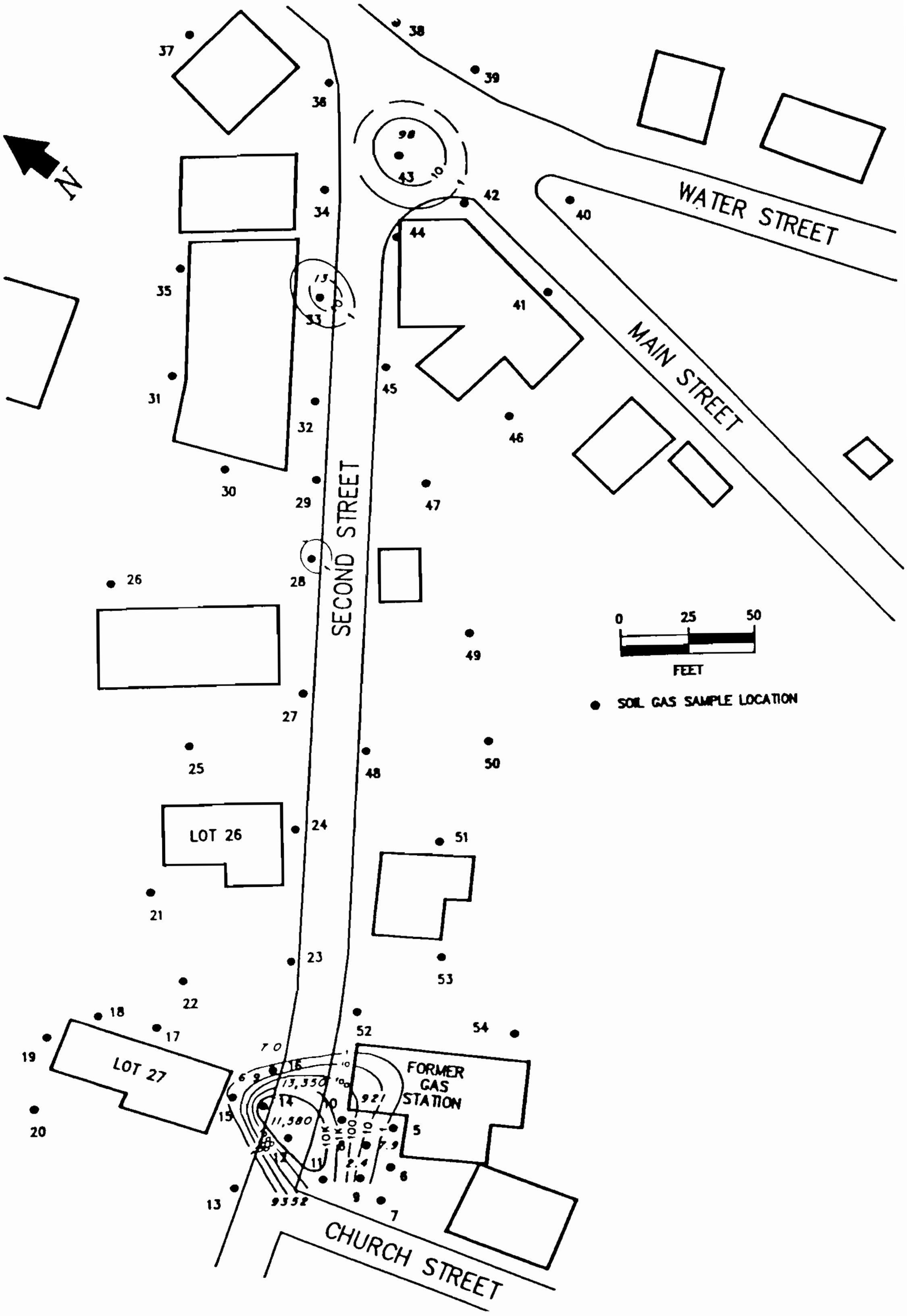


Figure 4. Typical contour map display of soil gas Total Volatile concentrations in ug/L for a survey done along a street to locate potential sources of petroleum hydrocarbons observed in groundwater (from Target, 1989).

# Well Sampling Methods, Costs, EPA Protocols

*By Bren Huggins*

**Hatcher-Sayre, Inc.**

## 1.0 *INTRODUCTION*

The ever increasing public concern surrounding the protection of groundwater resources and the advancing knowledge and in technical expertise of regulatory agencies have more than ever placed those who monitor the quality of groundwater in a position of accountability. At the very heart of this matter lies the necessity for correct and consistent groundwater sampling techniques. It is the data obtained during sampling activities which is used by the regulatory agencies to determine if a problem exists and, if so, the degree of that problem. For this reason, correct and consistent groundwater sampling techniques are essential to a successful and cost effective groundwater sampling program. A variety of acceptable sampling methods exist, though their applicability may vary on a site to site basis. For this reason, sampling programs should be designed in accordance with USEPA and State guidelines. Use of such guidelines will aid in ensuring the validity and cost effectiveness of the sampling program.

## 2.0 *OBJECTIVES OF THE GROUNDWATER SAMPLER*

Too often neglected are the objectives of the groundwater sampler. The groundwater sampler has two primary objectives which are as follows:

1. To obtain a representative sample of the aquifer water.
2. To minimize any changes in the chemistry of the sample during its transport from the wellhead to the laboratory.

The first objective appears simple enough. However, the sampler's first objective is, in itself, contradictory. A single sample is not, in itself, representative, hence the necessity of acquiring a population of samples which can be reviewed statistically. However, the sampler is charged with collecting, as near as possible a groundwater sample which reflects the chemistry of the aquifer at that particular location and point in time. Ensuring that fresh formational water from the aquifer is collected is the sampler's first task. In addition, changes in the chemistry of the sample will begin immediately upon its removal from the aquifer system in response to its changing environment. It is at this point that the sampler must address his or her second objective which is to minimize the altering of the sample chemistry prior to its arrival at the laboratory. Guidelines have been established in order to aid the sampler in meeting the above stated objectives. Two such examples are the USEPA Regional Standard Operating Procedures and the USEPA RCRA Groundwater Guidance Document.

## 2.1 *EPA PROTOCOLS—THE MEANS TO THE OBJECTIVES*

Though EPA groundwater sampling protocols are not comprehensive in their treatment of groundwater sampling, they do provide a firm foundation in which sampling programs should be designed. In addition, they provide a means of standardization to a relatively young and dynamic science. As mentioned previously, the EPA Regional Standard Operating Procedures and the RCRA Groundwater Guidance Document are two primary sources of such information. Both documents address well purging techniques, sample collection techniques, sample preservation and handling, documentation and decontamination procedures, all of which are essential to a legitimate sampling effort. In order for the sampler to obtain a "representative" sample, fresh formational water must be drawn into the well. An improperly purged well may yield highly misleading data as the samples collected will most likely show erratic results and will show little chemical resemblance to the water within the aquifer. Similarly, if the sampler's equipment is not properly decontaminated, constituents not present in the aquifer may appear in the sample analysis, again casting doubt on the validity of the data, which may result in additional sampling efforts. Following collection of the sample, proper handling must be observed in order to minimize any changes to the chemistry of the sample. Finally, every step of the sampling activities should be properly documented. This documentation includes all field notes and the chain of custody forms. Such documentation may, in some cases, be the only means of proving the credibility of a sampling program at a subsequent date. The guidance provided on these subjects in the EPA documents is highly valuable, though general. During the development of a sampling program, the information provided in these documents should be supplemented by consultation with the applicable regulatory agency. This will provide further credibility to the sampling effort and will aid in circumventing any future questions, disputes or litigation efforts.

## 2.2 *QUALITY ASSURANCE/QUALITY CONTROL—A MEANS OF CHECKING PERFORMANCE*

The accuracy of a sampling program is measured by quality assurance and quality control efforts. These include the following:

1. The collection of trip, field, and equipment blanks.
2. In-situ analyses
3. Laboratory QA/QC procedures

4. Comparisons with previous data

Trip blanks are samples prepared by the laboratory and usually consist of deionized water. They are shipped from the laboratory with the empty sample containers and returned to the laboratory with the samples collected. Trip blanks aid in establishing if the samples or the containers were contaminated during shipment. Field blanks consist of deionized water which is transferred to a clean sample container in the field. An analysis of the field blank aids in establishing if ambient field conditions may have effected the groundwater samples. Equipment blanks consist of deionized water which is poured over the sampling equipment and collected in a clean sample bottle. Analysis of the equipment blank aids in establishing if the sampling equipment was properly decontaminated.

In-situ testing of the groundwater for conductivity, temperature and pH can be used to establish if the well has been properly purged. These measurements should be taken at regular intervals during purging. Once the measurements remain consistent within a small margin of error, the sampler can be confident that he/she is sampling fresh groundwater.

Laboratory QA/QC procedures include equipment blanks and "spiked" samples which are prepared internally to confirm that the laboratory equipment has been properly cleaned and that the test methods are being carried out correctly.

Finally, graphical comparisons of newly acquired data with previously obtained data aid in quickly spotting anomalous results. If, for instance, a seasonal pattern has been observed in the data and a recently collected sample deviates considerably from this pattern, all previously discussed QA/QC checks should be carefully reviewed to establish if the result was legitimate.

All of the QA/QC methods discussed above aid in determining the accuracy of the data collected. These methods ensure that the objectives of the groundwater sampler have been met and truly representative data has been collected.

## 3.0 *SELECTED SAMPLING METHODS*

A wide variety of acceptable groundwater sampling methods are available. The most commonly used devices are bailers and pumps due to their reliability and simplicity. However, more sophisticated systems have been developed which are capable of isolating discrete monitoring zones within a well. One such system is the MP System designed by Westbay Instruments, Ltd.

The oldest and most frequently utilized system of sample retrieval is the bailer (Figure 1). Bailers are available in a multitude of sizes and materials. Due to their low discharge capacity and labor intensive use, they are most commonly utilized in purging and sampling shallow, low yielding monitoring wells. In order to avoid the cost of decontaminating bailers between sampling efforts, it is a common and cost effective practice to dedicate a bailer to a particular well.

A variety of sampling and purging pumps are available over the market today. Because it is essential that the water being sampled not come in contact with mechanical parts or air in the case of air lift pumps, a multitude of peristaltic, hand driven and air driven bladder pumps have been developed. Due to their versatility, relatively low cost and adaptability as dedicated systems, teflon bladder pumps have gained popularity in the sampling industry (Figure 1). Bladder pumps consist of a teflon, PVC or stainless steel cylinder which is closed at either end. An opening at the bottom of the cylinder followed by a check-value allows the entry of the groundwater into the pump. An alternating suction/surging action is induced in the internal teflon bladder using compressed air which is regulated by a control box. The deflation of the bladder draws water into the pump while the expansion of the bladder closes the foot value and forces water out of the discharge line. Bladder pumps are by their nature low discharge pumps and the discharge rate decreases with depth. The most efficient of the pumps manufactured today are satisfactory to depths of roughly 100 feet with 25 feet of head. Bladder pumps are most cost effective when used in long term sampling programs.

For large scale and lengthy hydrogeologic investigations where several different contaminants are present and/or complex geologic conditions exist, more sophisticated systems of sampling have been developed. Such systems may integrate both the well casing and the sampling device. One such system is the MP System developed by Westbay Instruments, Ltd. (Figure 2). The MP System utilizes a series of monitoring ports in the well casing which are separated and isolated from each other by either formation packers or a bentonite seal. Each set of monitoring ports is exposed to a discrete section of aquifer. Downhole tools are then utilized to take measurements to pump or purge a discrete zone or sample a zone. In this way, a single boring can be utilized to monitor numerous discrete intervals within the aquifer as opposed to installing numerous conventional monitoring wells. Due to the substantial cost of the specialized casing and down hole tools, systems such as the MP System become more cost effective as the depth of investigation, the number of zones to be monitored and the duration of the investigation increase. Under the proper circumstances, such systems can save the owner/operator considerable costs.

## 4.0 *THE COSTS OF GROUNDWATER SAMPLING*

The cost of groundwater sampling is primarily effected by the following variables:

1. The number of sampling points required
2. The number of analytical parameters

3. Volatility and stability of the compounds.

Obviously, the greater the number of sampling points, the greater the sampling cost to the owner/operator. Therefore, every effort should be made to minimize the number of wells installed while maximizing the amount of information generated from each installation. "Penny pinching" in the early stages of an investigation almost invariably results in replicating efforts and in increased long term costs. A few properly positioned and installed monitoring wells are far more valuable and cost effective than a large number of poorly constructed wells. The maxim in monitoring well installation is "do it right the first time and you won't have to do it again".

The number of analytical parameters required will vary on a site to site basis. Great care should be taken in negotiating which constituents should be analyzed. This is particularly crucial in long term sampling programs (i. e $\geq$ 30 years) in which substantial costs can be saved by decreasing the analyses required. In many cases, a few general indicator parameters can be analyzed in lieu of a large analytical suite. These indicator parameters may include conductivity, pH, TOX (total organic halogen) TOC (total organic carbon) and BOD (biological oxygen demand). These analyses are relatively inexpensive and may be used to indicate if contamination exists. If contamination is suspected to be present, more detailed analyses can be conducted to confirm and define the problem.

Because elaborate handling procedures must be utilized when sampling for highly volatile and unstable compounds, sampling for volatile and unstable compounds is more costly than analyzing for more stable compounds. Volatile organic compounds such as benzene, toluene, trichloroethylene and other common solvents fall into this category. Decreased holding times, special handling procedures and the high toxicity of these compounds which requires low limits of detection all result in cost increases relative to sampling and analysis.

## 4.1 *COST MINIMIZATION*

There are four primary means of minimizing sampling costs which are as follows:

1. Proper well installation
2. Use of indicator parameters
3. Consistency in the Sampling Program
4. Proper documentation

As discussed previously, proper well installation is the first step in a cost effective monitoring program. An improperly installed well may result in false positive results, inconsistent analytical results, litigious disputes and may significantly increased long term costs. It is more prudent to spend the necessary money to properly install wells in the early stages of the investigation than it is to cut corners initially and encounter increased long term costs.

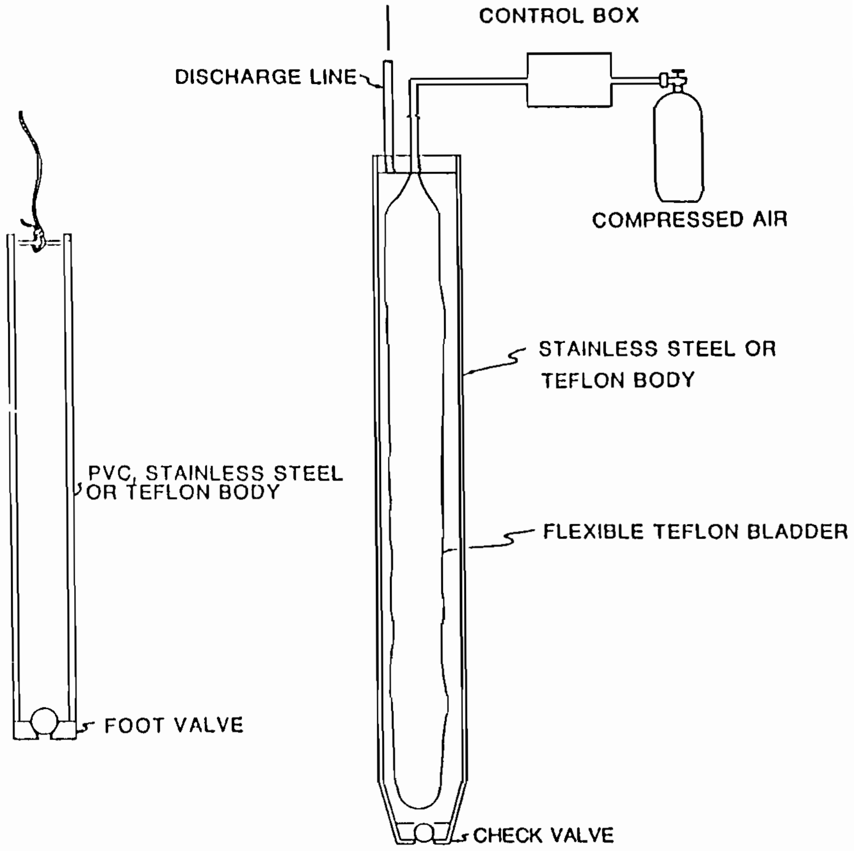
As mentioned previously, the use of indicator parameters can significantly reduce long term costs. EPA guidance documents can be used to identify when such an approach is feasible. Again, this approach should be discussed with and verified by the regulatory agency involved in the monitoring program.

Consistency in the sampling program and proper documentation are essential to the cost effectiveness of a groundwater monitoring program. Consistency in the sampling methods aids in ensuring a quality sampling effort each time and reduces the need to replicate sampling activities. Similarly, the quality of the sampling effort is in retrospect, only as good as the documentation which supports it. Detailed field records and chain of custody forms must be retained in order to safeguard against possible future attacks on the integrity of the monitoring program, future costs created by replication, and potential litigation.

## 5.0 *CONCLUSION*

Now more than ever, the owner/operator of groundwater monitoring systems is held accountable for using proper procedures by the public and by the regulatory agencies. Protocols presented in EPA guidance documents should be followed to ensure the credibility of the sampling program. The sampling methods utilized and the analytical testing required will vary depending on the site conditions. However, sampling costs can be reduced by minimizing the replication of previous efforts. Proper monitoring well installation, the use of proper and consistent sampling techniques, and proper documentation of the sampling activities can greatly aid in minimizing costs and circumventing any future replication of efforts while safeguarding against the threat of litigation.

FIGURE 1
COMMONLY USED SAMPLING DEVICES

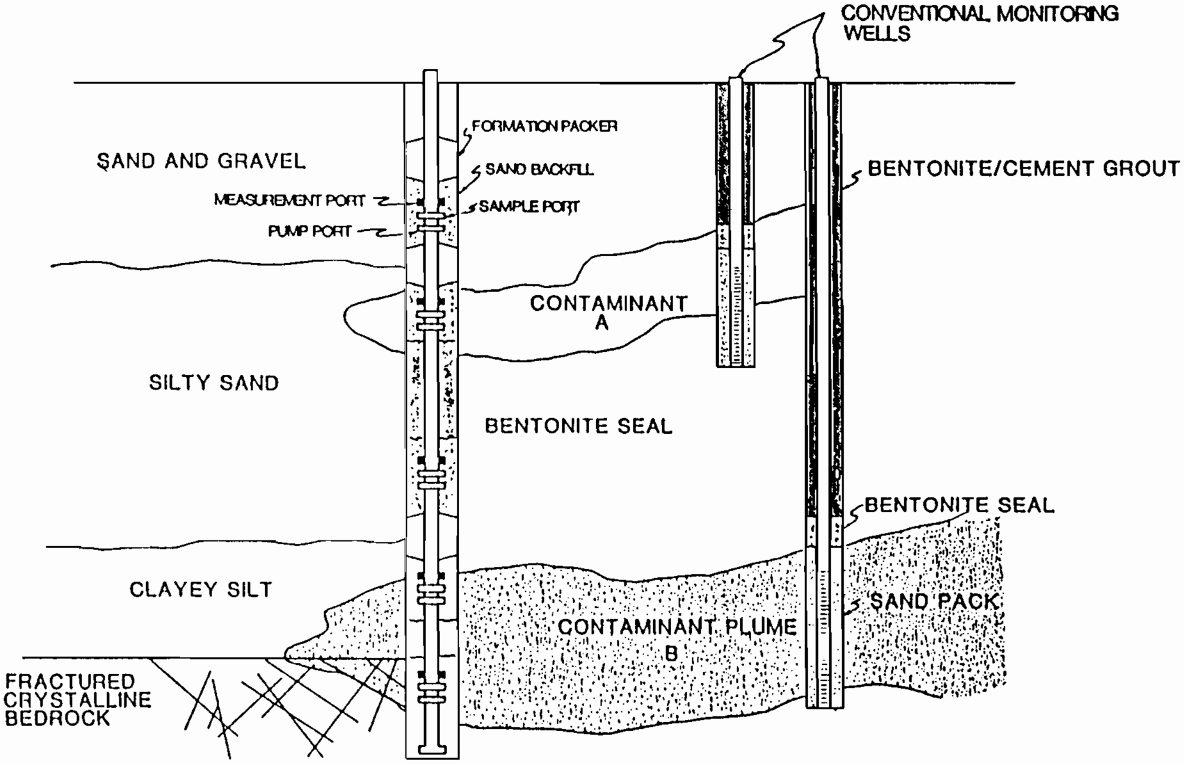


1. BAILER 2. BLADDER PUMP

# FIGURE 2

# MP GROUNDWATER MONITORING SYSTEM

3. THE MP SYSTEM
(WESTBAY INSTRUMENT,LTD.)



# Problems with Current Environmental Analytical Methods

*Edwin Cox III*
**Commonwealth Laboratory, Inc.**

As producers of fertilizer you are accustomed to exact numbers. Not only are you accustomed to them—you must have them. Heavy penalties (if you fail to meet guarantees) require them. Further, manufacturing practices always require that numbers be rapidly obtained, be accurate, and that they be generated by methods standard throughout the industry.

I do not say that in all cases you like the sampling or the analytical procedures, but they are standard and accepted.

In short, you look to chemists and samplers for exact numbers.

This afternoon I shall speak to you about some of the problems with EPA methodologies—the accuracy and precision. (You have already heard from geologists about the problems in sampling. )

## *TOTAL PETROLEUM HYDROCARBONS*

For example, for the determination of Total Petroleum Hydrocarbons (TPH) (oil and soil) there is a standard available of TPH in sludge. The sample has a true value of 70,000 mg/kg. The allowed range, for laboratories using this as a check sample, is between 1,300 and 140,000 parts per million. These are the 95% confidence limits within which good laboratories will get those results. This is a range then of 0. 13% to 14% of the measured amount. Thus an answer between 2% and 200% of the true value is acceptable.

## *COMPUTER MODELLING—DISSOLVED OXYGEN*

Now let us look at some of the problems in interpreting analytical results. I have mentioned the 95% confidence limit. (There is no such thing as 100% confidence that something is true. ) Sitting here we might agree with 100% confidence within this room that the world is round, but we all know that this is not exactly so. We have only a certain percent confidence in its being round although if we were to say "almost round" we would be quite happy with that description. In a recent study completed for a regulatory agency we stated that we had 95% confidence, based on 400 runs of a simulated situation, that the dissolved oxygen in a stream would never be less than the required minimum. The regulator interpreting these results read them the other way—that there was a 5% guarantee that we would always violate the minimum standards. I am not going to argue the merits and demerits of computer modeling or of confidence limits. I simply cite this as a problem area—how do you handle the situation?

Yesterday John Kohler discussed the role of TVA in developing new methods and in getting some order out of the chaos in environmental methodology. This is necessary—we can only wish him "God Speed".

## *METALS*

In the analysis of metals some people use atomic absorption and others use plasma analyses. Plasma is much cheaper. A problem in the analysis of metals is that when knowns are added to the matrix to determine percent recoveries—spiking—we are not able to put the known into the matrix of the original sample. For example, if we are spiking a sample with arsenic and the original arsenic was there as a lead alloy, we do not have a standard of arsenic in lead so that our spike recovery is not actually from the same matrix. (By using overly strong acids in our extractions, we should get the data we need.) It is possible to get reliable EPA recoveries or "checks" and to get very, indeed remarkable, reproducibility for duplicate samples while at the same time getting the wrong answers.

Cost for metals analyses range from $16 for 18 metals to $35 per metal depending on:

(1) The matrix, whether it be water, soil, oily waste, etc.

(2) Interferences

(3) The sensitivity desired—how low? Some regulations require that fractions of a part per billion be reported.

## *ORGANICS*

If you are interested in organics GC/MS (gas chromatography/mass spectroscopy) will give you hundreds of organics on a probability of 1-10. Standards are hard to get other than for the priority pollutants.

Pesticides and herbicides require complicated analyses.

Mr. Kohler, if TVA can get a list of the labs by specific skills in each pesticide/lubricide, this would be most helpful. No one laboratory can analyze for all of the many commercial chemicals of agriculture.

## *QUALITY CONTROL*

I should like to speak a moment about quality control in a laboratory. The EPA requires that a spike sample, a check sample, and a duplicate be run for every ten samples. Some laboratories boast that their quality control is presided over by a person not in the laboratory chain—a person who does not actually work with the analysts. I need but remind you of the current controversy about Japanese methodology versus US methodology in production. If a laboratory is producing analyses, then we can draw comparisons—teamwork in the laboratory, with every person devoted to quality control and assurance, under the supervision of the laboratory director, is far superior to any outside inspection procedure.

## *CLP LABORATORIES*

You may have heard of "CLP" laboratories as though these were certified laboratories. CLP stands for Contract Laboratory Program. Laboratories have CLP recognition so that they can do work for the EPA. This is a highly competitive bid situation and these laboratories are certified to perform either organic, or inorganic analyses, or both. The inspections to qualify are stringent. But simply being a CLP laboratory requires specificity. (The designation is a wonderful solicitation tool. The value of their numbers is no better than any other laboratories.)

Since the laboratories are contracted to the Federal government, and at a minimum price, their cost to the outside are often far higher than they are to the Federal government.

(1) CLP requires a detailed review of methods, re quires overly wordy reports and documenting that a laboratory did what it was supposed to do.

(2) When discussing services, ask if the CLP laboratory is approved in organics or inorganics as you might require.

(3) Is the laboratory currently a CLP laboratory? (No one announces when they leave the program.)

(4) Is CLP laboratory so named because it is an EPA contractor.

(5) Is the laboratory a free agent? Will it fight for you in court or will it side or yield to the EPA? Will it challenge EPA data if it is necessary in negotiations?

(6) Does it "process" samples or does it treat a customer as a customer? Is it interested in your samples? Does it understand your problem? Does it know or ask about peculiarities on your site and the reason you need the analyses?

(7) Does it do timely work (to include getting written reports out)?

(8) Are the costs competitive? The CLP program for many is a "lost leader" to get other work, and this other work must bear the cost of the heavy discounts given to the United States Environmental Protection Agency.

## *SELECTING A LABORATORY*

In selecting a laboratory, consider:

(1) That laboratory have a good reputation in your area.

(2) That it have a good reputation with a regulatory agencies and has such approvals as required.

(3) That it offer competitive, not necessarily the lowest, prices.

(4) That it be willing to appear at hearings and represent your interest and has the people to do it.

(5) That it understands your problems.

(6) That it is a full service laboratory. That it does the work in-house and can sample as necessary.

## *SUMMARY*

In summary, the methods of environmental work are not as good as you are used to and as you want.

CLP laboratories may be good for you but CLP status does not warrant this.

Select a laboratory like you do any supplier of services.

Do not allow the purchasing agent to select a laboratory on price. Worse do not let a purchasing agent change labs regularly for price differentials—you need a working relationship with your laboratory.

Thank you for your courteous attention.

# Thursday, November 2, 1989

## Session V
## Moderator:

## James Greene

## Operation of a Fertilizer Superterminal

*Harold D. Blenkhorn*
*and*
*Jack C. Ride*
**Nitrochem, Inc.**

In 1986, Nitrochem opened a year-round, deep-water, dry bulk materials terminal at Contrecoeur, Quebec, under the name of Chemport. This facility is operated as a division of Nitrochem. Inc.

Nitrochem has been a manufacturer and distributor of nitrogen materials in eastern Canada and north-east U.S.A. since its establishment in 1961. A retail fertilizer division operated under the name of Nutrite Inc. was acquired in 1967. The nitrogen complex located in Maitland, near the city of Brockville in eastern Ontario, initially produced ammonia and ammonium nitrate, with urea production facilities being added in 1966. As was the case with many North American urea manufacturers, the operation of this plant became uneconomical due to production costs relative to prices of imported product, and was forced to close in 1983. Nitrochem's entry into the business of handling bulk materials came about by the necessity to fulfill agricultural and industrial market requirements with imported urea.

Following the closure of the urea plant, the initial shipments of imported product were delivered to the Port of Montreal and handled through leased warehouses—an arrangement which accomplished the immediate purpose but had many disadvantages. Overall costs of handling and distribution were high due to storage fees and the necessity to truck the product from dockside to warehouse. Another disadvantage was physical deterioration of product due to multiple handling.

An investigation of alternatives to the existing operation led to discussions with Iron Ore Company of Canada (IOC) concerning a dock which they operate at Contrecoeur, located on the St. Lawrence River, about 35 kilometers east of Montreal. This facility, known as the "IOC Transfer Dock", was originally built to serve as a transfer point for iron ore concentrate from sea-going to shallow draft vessels for movement to Great Lakes ports.

**IOC TRANSFER DOCK**

| | |
|---|---|
| **Dock** | |
| Length | 1500′ (two berths) |
| Draft | 35′ |
| Equipment | Two travelling towers with 7.5 cu. yd. clams<br>Outreach: 57′<br>Travel center to center: 476′ |
| **Bulk Materials Discharge** | |
| 1,200 MT max/hr. free digging | |
| 2,000 MT max/hr. self-unloading | |

As a deep water, year-round port, with rail access and an existing vessel unloading system, the IOC dock represented an excellent situation for the establishment of a high-efficiency bulk materials handling operation. In addition to being located in a highly industrial area, the site also is centrally located to the Quebec fertilizer market—consumption within an 80-kilometer (50-mile) radius of Contrecoeur is about 300,000 tonnes. A 100-mile radius reaches to Eastern Ontario, Northern Vermont and North-East New York, for a total of some 450,000 tonnes. Since the IOC dock had been under-utilized during recent years, it was to the mutual advantage of IOC and Nitrochem to seriously explore the possibility of integrating a large capacity fertilizer terminal into the transfer dock operation. The possibility became a reality through an agreement reached in 1986 with IMC Fertilizers Inc. to receive and store rail and vessel deliveries of phosphate and potash materials for distribution to the Quebec market area.

The combined storage capacity required for IMC products and urea imported by Nitrochem amounted to about 100,000 tonnes. An original concept of a single structure "barrel" type warehouse was rejected in favour of nine individual domes, each with a capacity of about 11,000 tonnes. This approach provided the combined advantages of isolated storage for the diversity of products to be handled, economy of construction, and adaptability for future expansion.

Construction of the storage complex began in August 1986. Delivery of the first vessel shipment was taken in November. The essential features (see Figure 1), of the terminal are an overland conveyor leading from the IOC dockside facilities to a stacker which is central to a circular arrangement of nine storage domes.

**CHEMPORT FACILITIES**

| | |
|---|---|
| **Conveyor Phase I** | |
| Main belt | 1050′ × 48″ |
| Stacker | 241′ × 48″ |
| Rated Capacities | 2,000 MT max/hr. |
| **Storage Domes Phase I** | |
| Diameter | 142′ |
| Cement walls | 7′ |
| Height from ground level | 74′ |
| Capacity (Basis 70 lb./cu.ft.) | 11,000 MT |

**Truck Movement**

Dual 80′ 60 tonne capacity computerized truck scales to accommodate 500 MT/hr.

**Handling Modes**

Vessel direct to truck/rail
Vessel via conveyor to dome storage
Rail via conveyor to dome storage

The facilities also include a general utility building which serves as garage, scale house, offices and employee ameneties. A major initial acquisition was a frontend loader with a 3.5 in. yd. bucket for high-speed truck loading. A second smaller unit has since been added, which is largely dedicated to a urea bulk bagging operation. During the spring shipping season, extra payloaders can be obtained locally on short notice.

After a year of operations, it became evident that more storage capacity was required. Expansion of the facilities was justified by increased local demand for fertilizer materials storage, and an opportunity which developed to receive and store titanium ore for a local industry. Construction of four additional domes and conveyor extensions began in late 1988, becoming operational in the spring of 1989. The layout of the expanded facilities, (Phase II), is shown in Figures 1 and 2.

The performance of the terminal over a three-year period may be summarized by the following operational details and highlights:

**TONNES OF PRODUCT RECEIVED TO DATE:**

| | Storage | Direct Ex Vessel | Total |
|---|---|---|---|
| 1986 | 23,429 | 5,595 | 29,024 |
| 1987 | 152,613 | 32,575 | 185,188 |
| 1988 | 182,673 | 21,819 | 204,492 |
| 1989 est | 294,778 | 9,794 | 304,572 |
| TOTAL | 653,493 | 69,783 | 723,276 |

VESSELS: 45
UNIT TRAINS: 19

VESSEL UNLOADING RATE: 450 - 800 tonnes/hr.

**PRODUCTS STORED OR TRANSHIPPED**

- Prilled Urea
- Granular Urea
- Calcium Ammonium Nitrate
- Ammonium Sulphate
- Diammonium Phosphate
- Monoammonium Phosphate
- Triple Superphosphate
- Single Superphosphate
- Muriate of Potash
- Potassium Magnesium Sulphate
- Titanium Ore

**TRUCK SHIPMENTS**

| | Biggest Day May 16/89 (14 hrs.) | Biggest Week May 15 - 20/89 |
|---|---|---|
| No. of trucks | 230 | 1,020 |
| Total tonnes | 5,877 | 32,028 |

Average Loading Time: 3 min. 40 sec.
Loading Hours: 06:00 to 20:00

Note: May 16/89 Three payloaders 06:00 to 09:00
Two payloaders 09:00 to 16:00
Three payloaders 16:00 to 20:00

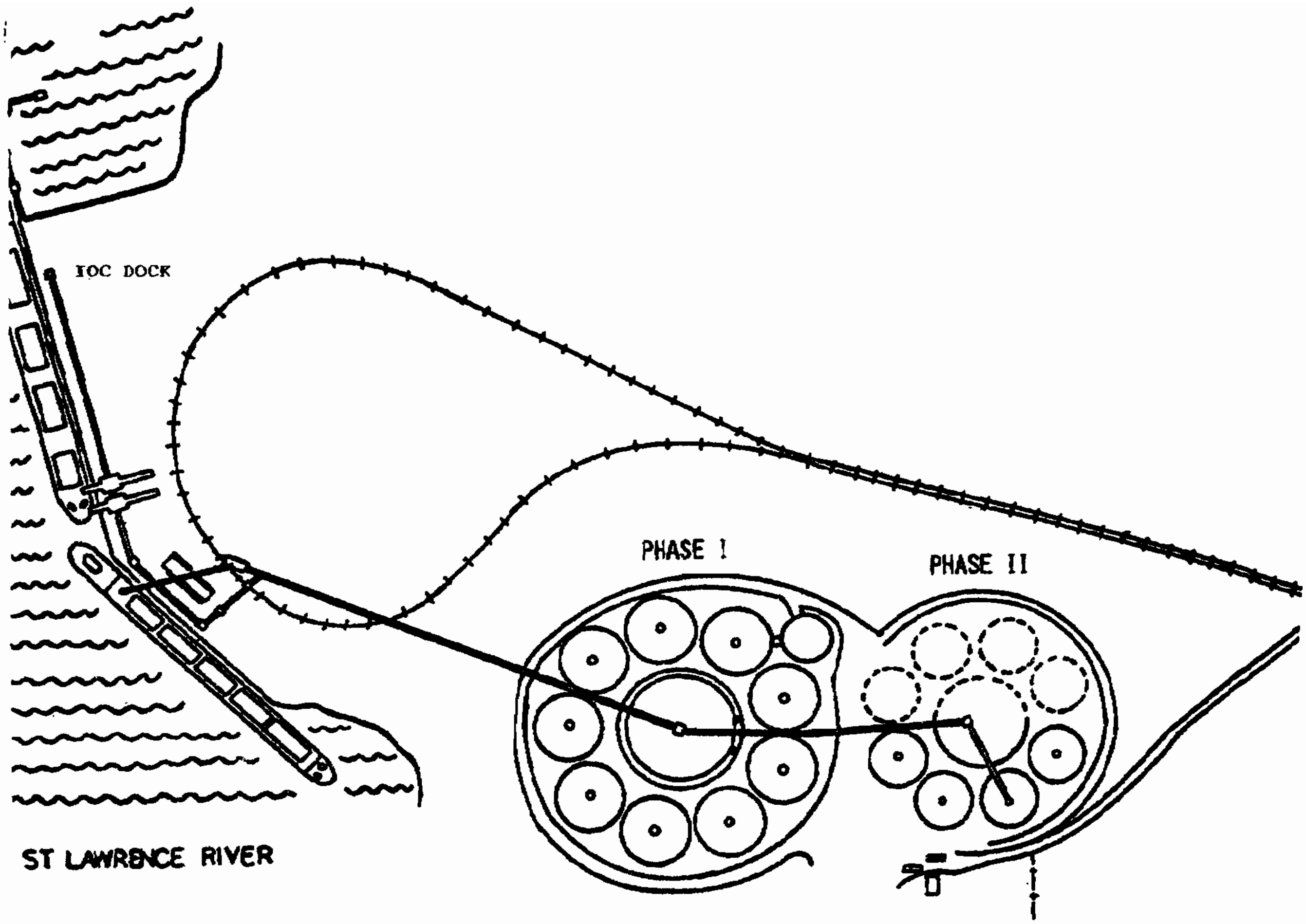


FIGURE 1 CHEMPORT, CONTRECOEUR, QUEBEC—OVERVIEW

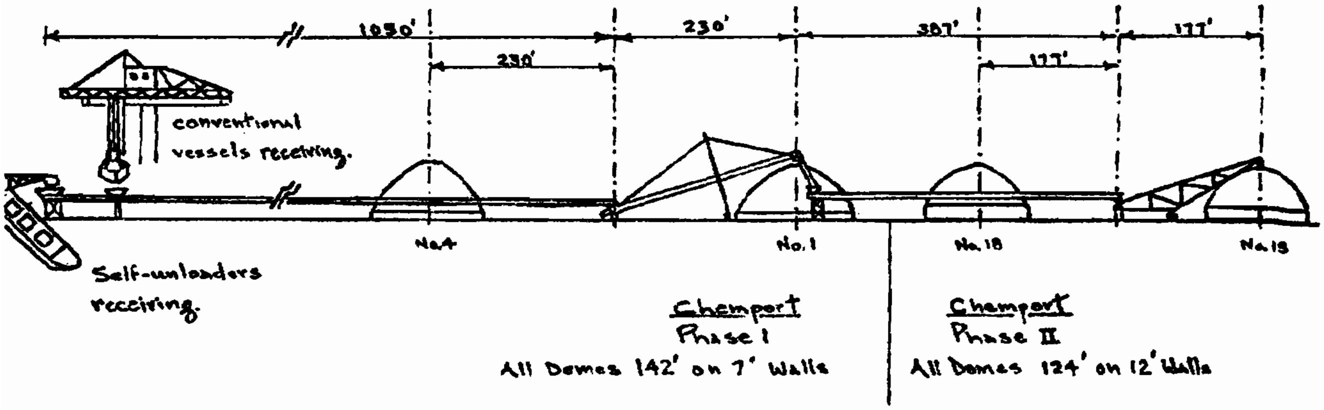


FIGURE 2 PROFILE OF CHEMPORT FACILITIES

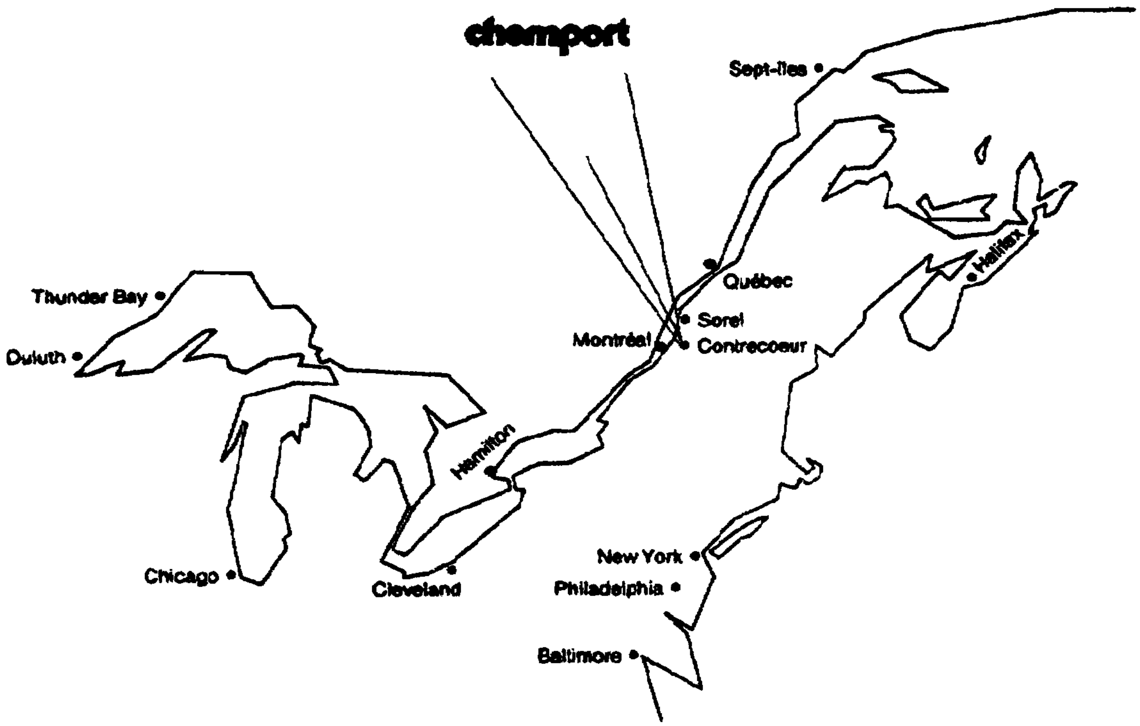

chemport
Sept-Iles
Québec
Sorel
Montréal
Contrecoeur
Halifax
Thunder Bay
Duluth
Hamilton
Chicago
Cleveland
New York
Philadelphia
Baltimore

FIGURE 3

# Comparative Properties of Urea-Based NPK Fertilizers

*By David W. Rutland*
*and*
*Jorge R. Polo*
**International Fertilizer Development Center**

## *INTRODUCTION*

The presence of urea in solid NPK fertilizers, either blends or granulated mixtures, usually has an adverse effect on the processing and storage properties of the product when compared with urea-free NPKs. At the 1977 Fertilizer Industry Round Table Meeting, Hoffmeister and Harrison presented data on the storage properties of various granular urea-based NP and NPK fertilizers (1); then at the 1984 Round Table Meeting, Rutland compared the hygroscopic and storage of selected blended and granulated NPKs containing urea (2); and finally, during the Round Table Meeting of 1985, four papers were presented dealing specifically with the granulation of urea-based NPKs (3,4,5,6).

This paper adds to the information on urea-based NPKs compared with NPKs that do not contain urea. First, comparative (bulk blending versus granulation) hygroscopic and storage property data on four of the most popular fertilizer grades used in the United States are given; second, critical relative humidity (CRH) data are provided for a number of fertilizer mixtures to help answer the question, "how much urea can be used in a solid fertilizer without adversely affecting its processing and storage properties?"; and finally, the processing restrictions that can be expected when urea is used in the production of granulated NPKs are described.

## *COMPARISON OF HYGROSCOPIC AND STORAGE PROPERTIES OF BULK-BLENDED AND GRANULATED NPKS-WITH AND WITHOUT UREA*

In the 1984 Round Table paper, the hygroscopic and storage properties of three fertilizer grades (28-28-0, 19-19-19, and 17-17-17) were reported (2). The study discussed in the paper was conducted to determine if there was a difference in physical properties between NPKs prepared by bulk blending and those prepared by granulation. In that study, the following two factors were used in selecting the materials for testing:

1. The bulk-blended and granulated NPKs should contain basically the same constituents (raw materials).
2. Urea should be used as the major source of nitrogen because the increasing use of urea to prepare multinutrient fertilizers had focused attention on the hydroscopicity and caking tendency of these properties.

As a result of this initial study, it was decided that a second series of tests should be performed using different grade and raw material selection criteria. Thus, four of the most popular grades used in the United States were selected for this evaluation. They were 10-20-20, 10-10-10, 8-32-16, and 6-24-24. Granulated versions of these four grades were obtained from commercial sources. Likewise, each of these four grades were prepared by bulk blending commercial fertilizer-grade granular raw materials. The samples were evaluated by analyzing each for CRH, moisture absorption-penetration, flowability, and caking tendency. All tests were performed according to procedures described in IFDC's *Manual for Determining Physical Properties of Fertilizer (7)*

## *RAW MATERIALS*

Raw materials to be used in the bulk blends were first selected by contacting TVA field staff located throughout the United States to establish which raw materials were most commonly used in their respective regions of the country to produce the four selected grades. Based on this survey, the raw materials used in preparing the bulk-blend grades were urea, ammonium nitrate, ammonium sulfate, diammonium phosphate (DAP), monoammonium phosphate (MAP), triple superphosphate (TSP), potassium chloride (KCl), potassium sulfate, and limestone filler. Each grade was then prepared using the selected granular raw materials according to three different formulation criteria. The first formulation for each grade was based on least raw material cost considering use of the selected raw materials. The second and third formulations for each grade were also based on least cost, but raw materials were selectively removed from consideration as an ingredient in that particular formulation to determine their impact on the properties of the particular grade. For example, formulation one for the 10-20-20 grade included urea, DAP, KCl, and limestone filler. Urea was selectively removed from consideration as an ingredient, and thus formulation two consisted of ammonium nitrate, DAP, KCl, and limestone filler. The composition of these products is shown in Table 1.

The granulated versions of these grades (obtained from commercial sources) were prepared by a number of conventional granulation techniques. The composition of these products is shown in Table 2. None of the granulated NPKs contained urea.

## *CRITICAL RELATIVE HUMIDITY (CRH)*

The CRH of a fertilizer material or a mixture of materials is defined as the relative humidity at which the material begins to absorb moisture from the atmosphere and below which it will not absorb atmospheric moisture. This test method involves exposing 2- to 4-g samples in aluminum cups (10 mm deep) to controlled humidity and temperature conditions in a standard laboratory environmental test chamber. The CRH values reported were determined at 30°C (86°F) (Table 3).

### *LABORATORY ABSORPTION-PENETRATION TEST*

Fertilizer materials vary in their ability to withstand physical deterioration (wetting and softening) when exposed to a humid atmosphere. Even materials with the same approximate CRH often behave differently as a result of differences in "moisture-holding capacity." To determine the physical quality of the fertilizer mixtures after exposure to humid conditions, a laboratory absorption-penetration test was performed by exposing samples for 72 h in open-top glass cylinders (6.8 cm in diameter by 20.0 cm depth) in a standard laboratory environmental test chamber at 30°C and 80% relative humidity. The values determined were moisture absorption, moisture penetration, moisture-holding capacity, and granule integrity (Table 3).

**Moisture Absorption** - Moisture absorption relative to the exposed surface is determined by weighing the samples and converting the measurement of absorbed moisture to mg/cm$^2$ of exposed sample surface.

**Moisture Penetration** - Moisture penetration is determined by visual observation through the glass walls of the cylinders. Values are reported as centimeters of moisture penetration depth into the samples. This is perhaps the most meaningful test because it provides a good indication of how deep atmospheric moisture will travel into a pile of exposed fertilizer and the amount of damage that can be expected by such wetting.

**Moisture-Holding Capacity** - Moisture-holding capacity of a fertilizer material is the amount of moisture that individual particles will absorb before allowing moisture to be transferred by capillary action to adjacent particles. A high moisture-holding capacity is considered a desirable characteristic if it does not adversely affect the granule integrity (strength). The moisture-holding capacity of each sample is calculated using the absorption-penetration data and the bulk density of the sample and reported as percentage (by weight) of absorbed moisture held by a material.

**Granule Integrity** - Granule integrity is determined qualitatively by handling the top surface layer of the sample (that which is in direct contact with the humid atmosphere) after exposure for 72 h and rating the granule strength as excellent, good, fair, or poor. This test, too, is very practical because it quickly tells if a granule will merely become wet on the surface but still retain its strength or if it will soften and collapse to form a wet, mud-like mass. Granule softening and collapse are usually more typical of granulated NPKs because they often are quite porus as a result of the evaporation of water during processing.

### *FLOWABILITY*

Flowability is the ability of a material to remain free flowing under humid conditions (in this case, 30°C and 90% relative humidity). The method involves charging a 500-cm$^3$ sample to a 20° -inclined rotating drum in a standard laboratory environmental test chamber. On the back wall of the inclined drum, four concentric circles are etched, marking the levels that 500-, 375-, 250-, and 125-cm$^3$ free-flowing samples will assume. As the fertilizer sample becomes moist, it will adhere to the sides of the drum. The free-flow time is measured as the time required for the material to become 25%, 50%, and 75% nonflowable (Table 3). This determination is made by noting the elapsed times as the 375-cm$^3$ (25% nonflowable), 250-cm$^3$ (50% nonflowable), and 125-cm$^3$ (75% nonflowable) marks become visible above the sample line.

### *CAKING TENDENCY (SMALL-BAG STORAGE TEST)*

Caking tendency is the tendency of a fertilizer to agglomerate or lump in storage. The caking tendencies of all samples are determined using a small-bag storage test. Each sample, measuring 1,800 cm$^3$ (about 2 kg), is placed in an essentially moisture-proof bag and subjected to a pressure of 0.28 kg/cm$^2$ (3.5 lb/in$^2$) at 30°C. Samples are evaluated after periods of 1, 3, 6, and 12 months' storage. After storage, the test bags are dropped twice (once on each thin side) from a height of 1 m. The contents of the bag are then carefully screened on a sieve (1.3-cm openings) to determine the percentage of lumps. Lump hardness is determined by crushing the lumps by hand and rating as light, medium, or hard. Prior to performing this test, the granulated NPKs and the bulk-blend raw materials are analyzed for moisture content. The moisture content of the bulk blends is calculated from raw material moisture analysis (Table3).

### *RESULTS*

Interpretation of data from Table 3 indicated the following major differences between the NPKs prepared by blending and those prepared by granulation:

1. When the raw materials in bulk blends and granulated mixtures were similar, the bulk blends were equal or superior with respect to CRH and moisture absorption, whereas the granulated mixtures were superior with respect to moisture-holding capacity and flowability. The major reason for these differences is probably the greater porosity of the granulated mixtures caused by the evaporation of water during the drying process. Greater porosity normally gives fertilizer a higher moisture-holding capacity and improved flowability characteristics. Conversely, the bulk-blend ingredients (especially urea and KCl) are much less porous and less prone to form a mud-like mass.

2. Granulated mixtures and bulk blends that did not contain urea or ammonium nitrate were generally superior (with respect to hygroscopic properties) to all bulk blends that contained urea and ammonium nitrate. This supports previously reported data indicating that urea- or ammonium nitrate-based NPKs are more hygroscopic than ammonium sulfate- or ammonium phosphate-based NPKs (1,2,8). The major reason for these differences is the less hygroscopic nature of ammonium sulfate and ammonium phosphates compared with urea and ammonium nitrate (7,8).
3. One urea-based blend that contained potassium sulfate was less hygroscopic than the same blended grade containing KC1. The major reason for this difference is the less hygroscopic nature of potassium sulfate compared with KC1 (7,8).
4. Bulk blends that contained ammonium nitrate had a stronger tendency to cake than did urea- and ammonium sulfate-based grades. Although it would be expected that ammonium nitrate-based grades would be more prone to caking than ammonium sulfate-based grades, no clear explanation can be given why they were also more prone to caking than the urea-based grades. One possible explanation is that the ammonium nitrate may have passed through the phase change that occurs at 32°C. Although the storage test was conducted at 30°C, there is some fluctuation of the temperature in the control chamber. This phase change at 32°C causes a change in the crystal state and, in turn, a sudden and significant change in volume, which may cause particle degradation during processing and storage (9).
5. Bulk blends that contained a mixture of DAP and TSP had a strong tendency to cake. This finding supports previously reported data indicating that DAP and TSP have limited compatibility (8). The caking is attributed to chemical reactions that occur between these two materials, especially in long-term storage. When ammonium nitrate was combined with DAP and TSP in a bulk blend, the tendency to cake was even more severe.

With respect to hygroscopic and storage properties, it can be concluded from these studies and previous studies (2) that the process (bulk blending or granulation) used to manufacture a particular fertilizer grade is not as crucial as the selection of the raw materials used in the process. However, when similar raw materials are used in either process, the bulk-blends seem to have slightly better storage characteristics.

## *EFFECT OF UREA ON THE CRH OF NPK FERTILIZER*

When urea is present in an NPK formulation, one can expect problems caused by the exaggerated effect that urea has on lowering the CRH of the mixture. The effect is more pronounced when KCI is present in the formulation. The presence of some secondary nutrients, for example, magnesium in the form of magnesium sulfate monohydrate (kieserite), further decreases the CRH of the mixture.

Low CRH values causes two types of problems. first, the fertilizer material becomes more hygroscopic and absorbs moisture from the atmosphere even when the relative humidity is quite low (505 or less), thus eliminating bulk handling and storage as an option in many locations unless dehumidification facilities are provided. Second the low CRH of urea-based mixtures greatly decreases the driving force for moisture evaporation during the drying step in the granulation process (10,11,12). This adversely affects the production capacity of the plant if it is not specifically designed for operation with low-CRH materials. The impact of low CRH values on processing parameters will be discussed in more detail later.

Despite these problems, interest in using urea to produce NPKs continues, especially in many developing countries where the use of straight materials is giving way to the demand for more complex fertilizer mixtures including those containing secondary and micronutrients. Thus, because urea is the most available and least costly source of nitrogen, its use is preferred, and a better understanding of peculiar characteristics it imparts to fertilizer mixtures is needed.

## *CRITICAL RELATIVE HUMIDITY*

The CRH of a fertilizer mixture can provide a useful point of reference in predicting the handling and storage properties of the mixture; moreover, such data can also be used to estimate the expected capacity of the drying and cooling system in a granulation unit that may be used to produce NPKs containing urea (10,11,12). For these reasons, the CRH (same procedure as discussed previously) of a large number of fertilizer mixtures was determined to better quantify the influence of the level of urea in the mixture as influenced by the other materials also present (Table 4).

## *RAW MATERIALS*

Raw materials used in these evaluations were prilled urea, granular DAP, and special standard KC1 obtained from commercial sources (Table 5). however, all raw materials were ground to pass a 180μm (80 U.S. mesh) sieve to facilitate intimate mixing and contact of the ingredients of each mixture. The mixtures were individually weighed and prepared immediately prior to each determination. The use of intimately mixed ground samples ensured not only more accurate CRH readings but also much quicker results (usually 3 h) than can normally be obtained with the granular mixtures (usually 24 h). Results are obtained more quickly because the increased surface contact of the ground particles accelerates any material interactions and, in turn, the rate of atmospheric moisture absorption. Even though the particle size of a material does not alter its CRH, the smaller particle size of a ground sample is more typical of the condition that would be expected during the drying process in an NPK granulation plant where the rate of moisture evaporation and/or absorption is of critical importance in estimating the expected performance (capacity) of the unit.

During initial CRH evaluations of the raw materials, it was discovered that the DAP and KCI samples had lower CRH values than expected (2,7,8). The most commonly reported CRH value for DAP is 70%-75% (at 30°C), whereas the CRH value for the tested DAP at 30°C was 60%-70%. Analysis of this DAP revealed the presence of urea nitrogen (Table 5). Urea or ammonium nitrate is sometimes used in some DAP production units to adjust the $N:P_2O_5$ ratio if impurities in the phosphoric acid interfere with the ammonium process. Therefore, there are probably two factors causing a lowering of the CRH in this sample: the presence of urea and a "higher than normal" level of the CRH in this sample: the presence of urea and a "higher than normal"level of impurities in the phosphoric acid.

Additionally, the most commonly reported CRH value for KC1 is 70%-80% (at 30°C), whereas the CRH value for the tested KC1 at 30°C was 50%-60%. Analysis of this particular sample of KC1 showed no significant difference from "higher CRH" KC1 samples (Table 5). Although no confirming data are available to explain this difference in CRH, it is believed by some potash producers that the difference can be attributed to the presence of a surface contamination of magnesium and sodium chloride (from process brine) concentrated on the surface of the "low-CRH" KC1 particles. Thus, the location of these impurities may be more important than the absolute quantity.

Because of these unexpected differences, two series of CRH evaluations were performed. One series of tests were performed using the "low-CRH" DAP and KC1 along with urea, and the other series of tests were performed using "high-CRH" DAP and KC1 along with urea (Table 4).

## *RESULTS*

Interpretation of the CRH data shown in Table 4 and illustrated in Figures 1 and 2 indicates the following:

1. Any level of urea in the three-component mixtures adversely affects the CRH values. Thus, even a very small amount of urea (as little as 2%) was noticeable in the mixture (Figure 2).
2. In three-component mixtures, the CRH values are essentially the same at levels of 20% urea and above, regardless of the urea: DAP:KCL ratio (of 14 mixtures in this category, 11 mixtures had a CRH of 45%-50% and three mixtures had a CRH of 45%-55%) (Figure 1).
3. In two-component mixtures, CRH values had the following general rating regardless of raw material ratios:

| **Mixture Components** | **Rating** |
|---|---|
| DAP + KCI | Best |
| Urea + DAP | Moderate |
| Urea + KC1 | Worst |

4. There was essentially no difference in the CRH values of three-component mixtures using either the "low-CRH" DAP and KC1 (mixture A) or the "high-CRH" DAP and KC1 (mixture B).
5. The only significant differences in the CRH values between mixture A and mixture B were in the two-component mixtures containing KC1.
6. These data confirm the empirical conclusions of the fertilizer industry that urea in excess of about 5% in an NPK granulation formula adversely affects the process and that the adverse effect of urea is magnified if KC1 is present in the formulation.

## *PROCESSING CHARACTERISTICS OF UREA-BASED GRANULAR NPKS*

As indicated earlier, interest in expanding the use of urea as a major source of nitrogen in NPK granulation plants continues. This interest is especially keen in many of the developing country locations where solid urea is the most available and most cost-effective source of nitrogen. Also, in many of these same countries, a trend is developing toward more complex fertilization practices including a number of granular NPKs containing secondary nutrients and micronutrients as an alternative to the use of traditional straight materials such as ammonium sulfate, calcium ammonium nitrate, urea, superphosphates, and the like.

## *THE PROCESSING PROBLEMS CAUSED BY UREA-CONTAINING NPKS*

In general, a granular NPK that contains urea is more difficult to manufacture and store when compared with its urea-free counterpart. The foregoing data further quantify this observation. The difficulties stem from the major effect that even a small amount of urea (as little as 2%-5%, as shown in Table 4 and Figure 2) has on (1) increasing the overall solubility of the granulating mass, (2) the lowering of the temperature that can be tolerated in the dryer to avoid "melting," and (3) the lowering of the CRH which in turn lowers the driving force for drying.

Additionally, because of its lower CRH, the urea-based material (and its associated dust) is also very hygroscopic and quickly becomes wet, thus leading to the plugging of screens, ducts, and chutes. The hygroscopic material also results in slippery floors and walkways and causes excessive corrosion of equipment and electrical systems. Some of these problems can be decreased or avoided by dehumidification of the process plant building. This, of course, is quite costly and to be effective requires a considerable amount of careful design, upkeep (maintenance), and housekeeping discipline.

### *IMPACT ON DRYING*

A complete discussion of the processing characteristics of urea-based NPKs is beyond the scope of this paper. However, a brief discussion of the impact that the presence of urea has on the performance of the dryer in a typical NPK granulation plant will help to illustrate one of the major disadvantages of using urea to produce granular NPKs. The drying process is selected for illustration because it represents the most costly equipment system in a granulation plant and its performance and location in the process with respect to the screens and cooler are difficult to change once it is installed. Thus, the drying process becomes the major bottleneck when urea is used in a plant not specifically designed for its use.

**CRH at Elevated Temperatures**—A knowledge of the CRH of the particular fertilizer product or mixture is essential when designing, evaluating, or predicting the performance of fertilizer dryers. In designing the dryer, use of CRH data based on ambient air temperature (30°C) can be very misleading and can result in a unit that fails to meet the specified product moisture content. This is illustrated by the large variations in the CRH of common fertilizer mixtures (Figure 3) as a function of temperature. At 30°-40°C, the CRH values of most fertilizers are in the range of about 45% to 75%; monoammonium phosphate (MAP) is the highest (75%), and the urea ammonium phosphate-based NPKs (UAP-NPK) and nitrophosphate-based products are the lowest at about 45% to 50%. However, when these materials are subjected to the elevated temperatures typically encountered in the drying process, the CRH values decrease rapidly and approach levels of about 25% for the UAP-NPKs and some of the nitrophosphate and ammonium nitrate-based fertilizers. The CRH is further depressed with the addition of certain secondary nutrient salts, for example, magnesium sulfate monohydrate (kieserite).

It is this CRH-temperature relationship, together with other important variables, that ultimately determines the design parameters required for a particular drying system. In addition to CRH, these design parameters include the (1) temperature and relative humidity of the ambient air, (2) solid material feed rate (throughput) and the evaporative load placed on the dryer, (3) retention time of material in the dryer required to achieve the desired product moisture level, (4) temperature sensitivity of the fertilizer, and (5) particle size and density of the fertilizer material and their relationship to the allowable gas velocity (airflow) that can be tolerated in the dryer. Of these, the relationship between the CRH and temperature sensitivity of the fertilizer and the relative humidity (RH) of the ambient air used for drying have the greatest impact. It is this relationship that ultimately determines the humidity driving force in the dryer (the difference between the CRH of the fertilizer and the RH of the air leaving the dryer) and therefore the capacity of the dryer.

**Temperature Sensitivity of the Fertilizer**—Not all fertilizers can be subjected to the same drying temperatures. Some urea-based NPK fertilizers start softening and become quite plastic at about 70°C. If the dryer exit temperature is increased above this point, the granules may become excessively plastic, leading to uncontrolled agglomeration (production of oversize), buildup on the dryer internals, and difficulty in handling, screening, and crushing. Other urea-based NPKs behave quite differently and simply disintegrate at elevated temperatures. On the other hand, many urea-free NPKs as well as DAP and MAP, can often be dried at temperatures near 100°C without showing any significant softening or deterioration.

**Dryer Capacity**—The combined effect of a low CRH and the increased temperature sensitivity characteristics of urea-based NPKs result in a lowering of the drying capacity for a given unit when compared with a urea-free product with more favorable CRH and temperature sensitivity criteria. In general, one can expect the capacity of a dryer designed to process urea-free NPKs to decline significantly when it is used to dry NPKs containing urea, especially if the amount of urea exceeds about 15%. As indicated earlier, the problem of decreased capacity becomes even greater if the formulation contains potassium chloride, magnesium sulfate salts (for example, kieserite), and certain other secondary and micronutrient materials.

An example of the very critical relationship between the CRH of the fertilizer material, the temperature and RH of the ambient air used for drying, and the capacity of a dryer of a given size and operating criteria is shown in Figure 4. These data show that at any given ambient air condition, assuming a constant dryer exit material temperature (79°C), the CRH of the fertilizer at the drying temperature (79°C in this example) is the factor that ultimately determines the dryer capacity (throughput) according to the indicated operating parameters. In this example, a 10 percentage point spread is maintained between the CRH of the fertilizer and the RH of the dryer exit air. Industrial experience has shown that a spread of 10 percentage points is about minimum, and a 15- to 20-point spread is preferred (5). In this example, there is almost a threefold difference in the drying capacity between the high-CRH DAP and the low-CRH urea-based NPK (17-17-17).

As indicated earlier, the foregoing is not intended to be an exhaustive examination of the effect of urea on processing NPKs. However, the data clearly indicate that caution should be taken when considering the use of urea in a granulation plant not specifically designed for its use.

## *CONCLUSIONS*

The evidence accumulated by carefully controlled laboratory evaluations together with empirical data gathered from industry experience clearly indicates that the presence of urea in a fertilizer mixture can be quite troublesome in regard to not only its influence on the storage and handling properties of a fertilizer, but also its impact on the manufacturing process.

The data presented in this paper together with data from other studies are intended to help quantify the impact of urea and assist those involved in the manufacture and handling of urea-based NPK fertilizers.

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**Table 1. Composition of Bulk Blends**

| Grade | Composition Code[a] | Urea (46-0-0) | Ammonium Nitrate (33-0-0) | Ammonium Sulfate (21-0-0) | Diammonium Phosphate (18-46-0) | Monoammonium Phosphate (11-54-0) | Triple Super-phosphate (0-46-0) | Potassium Chloride (0-0-60) | Potassium Sulfate (0-0-50) | Limestone Filler (0-0-0) |
|---|---|---|---|---|---|---|---|---|---|---|
| | | (% by wt) | | | | | | | | |
| 10-20-20 | BB-1 | 4.8 | | | 43.5 | | | 33.4 | | 18.3 |
| 10-20-20 | BB-2 | | 6.6 | | 43.5 | | | 33.4 | | 16.5 |
| 10-20-20 | BB-3 | | | 23.2 | 28.5 | | 15.0 | 33.3 | | |
| 10-10-10 | BB-1 | 13.3 | | | 21.8 | | | 16.7 | | 48.2 |
| 10-10-10 | BB-2 | | | 47.7 | | | 21.8 | 16.7 | | 13.8 |
| 10-10-10 | BB-3 | 13.3 | | | 21.8 | | | | 20.0 | 44.9 |
| 8-32-16 | BB-1 | | | | 44.5 | | 25.1 | 26.7 | | 3.7 |
| 8-32-16 | BB-2 | | 3.8 | | 37.4 | | 32.1 | 26.7 | | |
| 8-32-16 | BB-3 | | | | 17.1 | 44.8 | | 26.7 | | 11.4 |
| 6-24-24 | BB-1 | | | | 33.4 | | 18.8 | 40.0 | | 7.8 |
| 6-24-24 | BB-2 | | | | 12.8 | 33.6 | | 40.0 | | 13.6 |
| 6-24-24 | BB-3 | | 7.8 | | 19.1 | | 33.1 | 40.0 | | |

a. BB = bulk blend.

**Table 2. Raw Materials Used in Granulated NPKs**

| Grade | Composition Code[a] | Raw Materials |
|---|---|---|
| 10-20-20 | GM-1 | Sulfuric acid<br>Ammonia/ammonium nitrate solution<br>Ammonium sulfate<br>Phosphoric acid<br>Monoammonium phosphate<br>Potassium chloride<br>Sand |
| 10-10-10 | GM-2 | Sulfuric acid<br>Anhydrous ammonia<br>Ammonium sulfate<br>Phosphoric acid<br>Monoammonium phosphate<br>Potassium chloride<br>Sand |
| 8-32-16 | GM-3 | Sulfuric acid<br>Anhydrous ammonia<br>Phosphoric acid<br>Potassium chloride<br>Sand |
| 6-24-24 | GM-4 | Sulfuric acid<br>Anhydrous ammonia<br>Phosphoric acid<br>Potassium chloride<br>Sand |

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a. GM = granulated NPK mixture.

**Table 3. Hygroscopic and Storage Properties of Mixtures of Granular Materials (Bulk Blends) and Granulated NPKs[a]**

| Grade | 10-20-20 | | | | 10-10-10 | | | | 8-32-16 | | | | 6-24-24 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Type[b] and composition code[c] | GM-1 | BB-1 | BB-2 | BB-3 | GM-2 | BB-1 | BB-2 | BB-3 | GM-3 | BB-1 | BB-2 | BB-3 | GM-4 | BB-1 | BB-2 | BB-3 |
| Moisture content, %[d] | 0.8 | 1.2 | 1.2 | 1.2 | 1.3 | 0.6 | 0.7 | 0.5 | 1.3 | 1.6 | 1.6 | 1.2 | 1.2 | 1.4 | 1.1 | 1.4 |
| Critical relative humidity (30°C), %[e] | 60-70 | 65-70 | 60-70 | 65-75 | 65-75 | 60-65 | 70-75 | 65-70 | 65-75 | 70-75 | 65-70 | 65-75 | 65-75 | 65-75 | 65-75 | 55-65 |
| Laboratory Absorption-Penetration Test (30°C, 80% relative humidity for 72 h) | | | | | | | | | | | | | | | | |
| Moisture absorption, mg/cm$^2$ | 328 | 253 | 256 | 138 | 267 | 284 | 88 | 179 | 276 | 209 | 198 | 138 | 284 | 190 | 132 | 270 |
| Moisture penetration, cm | 3.6 | 7.4 | 6.8 | 2.3 | 3.8 | 11.4 | 1.6 | 7.4 | 1.5 | 1.9 | 3.3 | 2.2 | 1.9 | 2.2 | 1.9 | 4.8 |
| Moisture-holding cap., mg/cm$^3$ | 91 | 34 | 38 | 60 | 70 | 25 | 55 | 24 | 184 | 110 | 60 | 63 | 149 | 86 | 70 | 56 |
| Moisture-holding capacity, % | 8.9 | 3.4 | 3.6 | 6.0 | 7.1 | 2.4 | 5.1 | 2.1 | 18.8 | 10.9 | 6.1 | 5.8 | 14.7 | 8.7 | 6.5 | 5.7 |
| Granule integrity[f] | Poor | Fair | Poor | Poor | Poor | Fair | Exc[g] | Poor | Fair | Fair | Poor | Fair | Fair | Fair | Poor | Fair |
| Flowability (30°C and 90% relative humidity) | | | | | | | | | | | | | | | | |
| 25% nonflowable, min | 60 | 14 | 12 | 45 | 75 | 15 | 40 | 26 | 115 | 57 | 46 | 38 | 155 | 52 | 48 | 33 |
| 50% nonflowable, min | 87 | 20 | 19 | 75 | 90 | 22 | 60 | 35 | 140 | 75 | 60 | 50 | 175 | 67 | 70 | 42 |
| 75% nonflowable, min | 95 | 25 | 30 | 85 | 105 | 28 | 74 | 48 | 180 | 85 | 67 | 60 | 205 | 76 | 87 | 50 |
| Caking Tendency (small-bag storage test at 30°C and 0.28 kg/cm$^2$ pressure) | | | | | | | | | | | | | | | | |
| Percent +12.5-mm lumps/hardness[h] | | | | | | | | | | | | | | | | |
| 1 month | 0/- | 0/- | 6.9/L | 0.1/L | 0/- | 0/- | 0/- | 0/- | 0/- | 0/- | 11.1/L | 0/- | 0/- | 5.6/L | 0/- | 7.8/L |
| 3 months | 0/- | 0.1/L | 21.7/M | 2.8/L | 0/- | 0/- | 0/- | 0/- | 0/- | 6.1/L | 26.1/M | 0/- | 0/- | 24.2/M | 0/- | 34.4/M |
| 6 months | 0/- | 3.9/L | 25.0/M | 12.2/L | 0/- | 0/- | 0/- | 0/- | 0/- | 8.9/L | 50.6/H | 0/- | 0/- | 30.0/M | 0/- | 37.5/M |
| 12 months | 0/- | 9.4/L | 46.7/M | 16.2/L | 0/- | 0/- | 0/- | 0/- | 0/- | 9.4/L | 63.3/H | 0/- | 0/- | 31.0/M | 0.1/L | 50.0/H |

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a. All tests were performed according to procedures described in IFDC reference manual R-6.

b. GM = granulated NPK mixture; BB = bulk blend.

c. Refer to Table 1 for composition of bulk blends and Table 2 for composition of granulated mixtures.

d. Determined by vacuum desiccation (*Official Methods of Analysis*, 13th Edition [1980], AOAC, 2.013). All granulated mixtures and raw materials were analyzed for moisture content. The moisture content of the bulk blends was calculated from raw material moisture analyses.

e. Critical relative humidity measured by exposing samples for 24 h. Most samples were still absorbing moisture after the standard 3-h exposure period.

f. Granule integrity is a qualitative observation based on the strength of the surface granules after exposure for 72 h.

g. Exc = excellent.

h. H = hard; M = medium; L = light.

## Table 4. CRH Values of Mixtures of Urea, DAP, and KCl

| Sample Ratio (Urea:DAP:KCl) | CRH of Samples at 30°C | |
|---|---|---|
| | Mixture A[a] | Mixture B[b] |
| (% by wt) | -------(% relative humidity)------ | |
| 100-0-0 | 70-75 | 70-75 |
| 0-100-0 | 60-70 | 70-75 |
| 0-0-100 | 50-60 | 70-80 |
| 0-80-20 | 55-65 | 65-70 |
| 0-60-40 | 55-65 | 65-70 |
| 0-40-60 | 55-65 | 65-70 |
| 0-20-80 | 55-65 | 60-70 |
| 2-49-49 | 55-65 | 55-65 |
| 5-47.5-47.5 | 50-60 | 50-60 |
| 10-45-45 | 50-55 | 50-55 |
| 15-42.5-42.5 | 45-55 | 45-55 |
| 20-80-0 | 55-60 | 55-60 |
| 20-60-20 | 45-55 | 45-55 |
| 20-40-40 | 45-55 | 45-50 |
| 20-20-60 | 45-50 | 45-50 |
| 20-0-80 | 45-50 | 45-50 |
| 33.3-33.3-33.3[c] | 45-50 | 45-50 |
| 40-60-0 | 55-60 | 55-60 |
| 40-40-20 | 45-50 | 45-50 |
| 40-20-40 | 45-50 | 45-50 |
| 40-0-60 | 45-50 | 50-55 |
| 60-40-0 | 50-60 | 55-60 |
| 60-20-20 | 45-50 | 45-50 |
| 60-0-40 | 45-55 | 45-55 |
| 80-20-0 | 55-60 | 50-60 |
| 80-0-20 | 45-55 | 45-55 |

---

a. Raw material – Urea (0.3% HCHO), DAP (1.7% of total N as urea nitrogen), and KCl ("low CRH").

b. Raw material – Urea (0.3% HCHO), DAP (no urea nitrogen), and KCl ("high CRH").

c. Midpoint sample – 5 replicates were analyzed.

**Table 5. Composition of Raw Materials Used in Critical Relative Humidity Evaluations**

| Analysis[a] | Urea | DAP ("Low CRH") | DAP ("High CRH") | Potassium Chloride ("Low CRH") | Potassium Chloride ("High CRH") |
|---|---|---|---|---|---|
| (% by wt) | | | | | |
| Total nitrogen | 46.0 | 17.3 | 18.1 | - | - |
| Urea nitrogen | - | 0.3 | 0.0 | - | - |
| $P_2O_5$ | - | 44.9 | 46.4 | - | - |
| $K_2O$ | - | - | - | 61.1 | 61.2 |
| Magnesium | - | - | - | 0.3 | 0.3 |
| Sodium | - | - | - | 0.8 | 1.4 |
| Calcium | - | - | - | 0.02 | 0.02 |
| Organic carbon[b] | - | - | - | 0.0 | 0.0 |
| Total moisture | 0.1 | 2.3 | 1.9 | 0.2 | 0.2 |

a. *Methods of Analysis*, AOAC, 14th Edition (1984).

b. NFDC-TVA Laboratory Manual, 1979, Tennessee Valley Authority, Division of Chemical Development, Fundamental Research Branch, Muscle Shoals, Alabama.

**FIGURE 1. CRH of Urea-Based NPK Mixtures.**

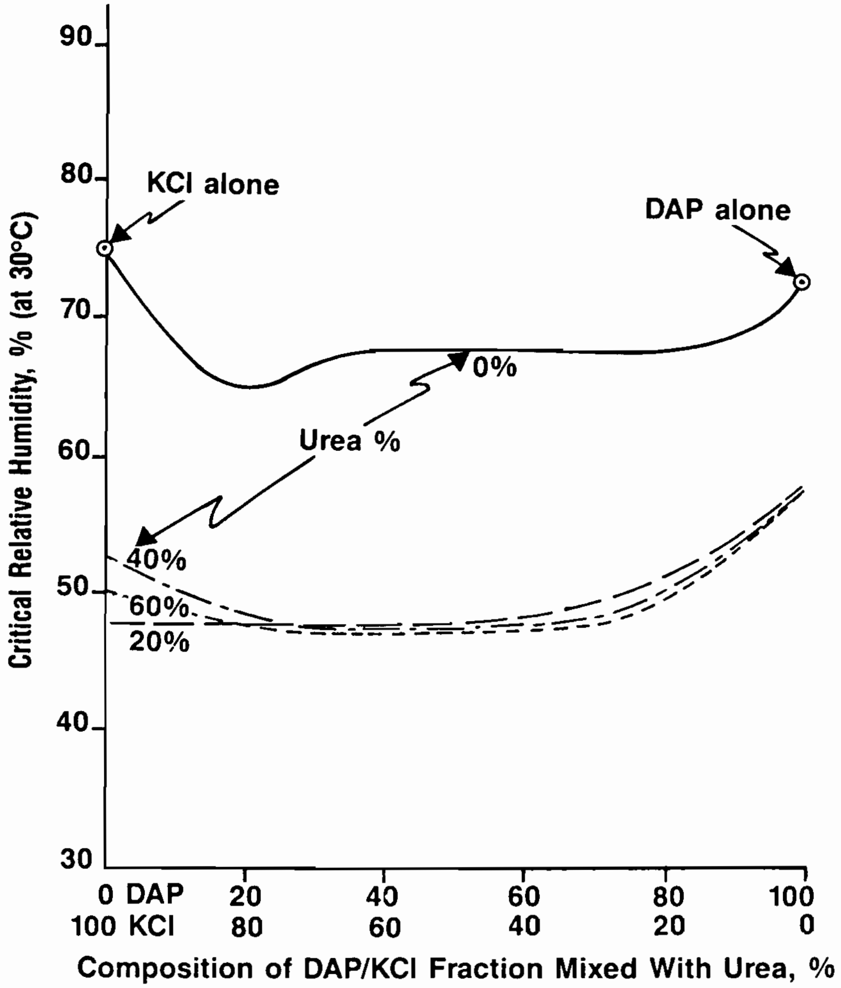


FIGURE 2. Effect of Urea on the CRH of Urea-Based NPK Mixtures.

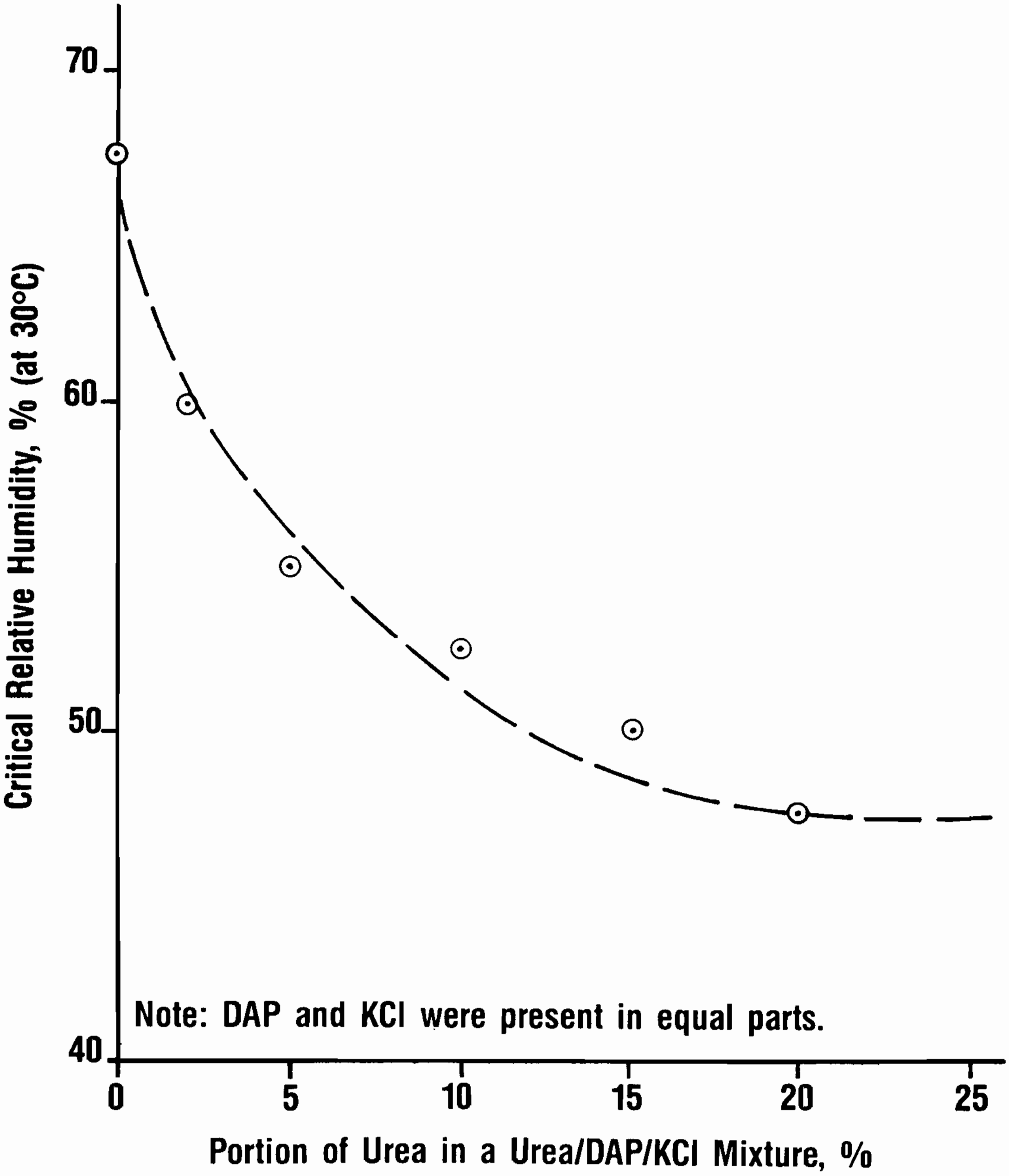
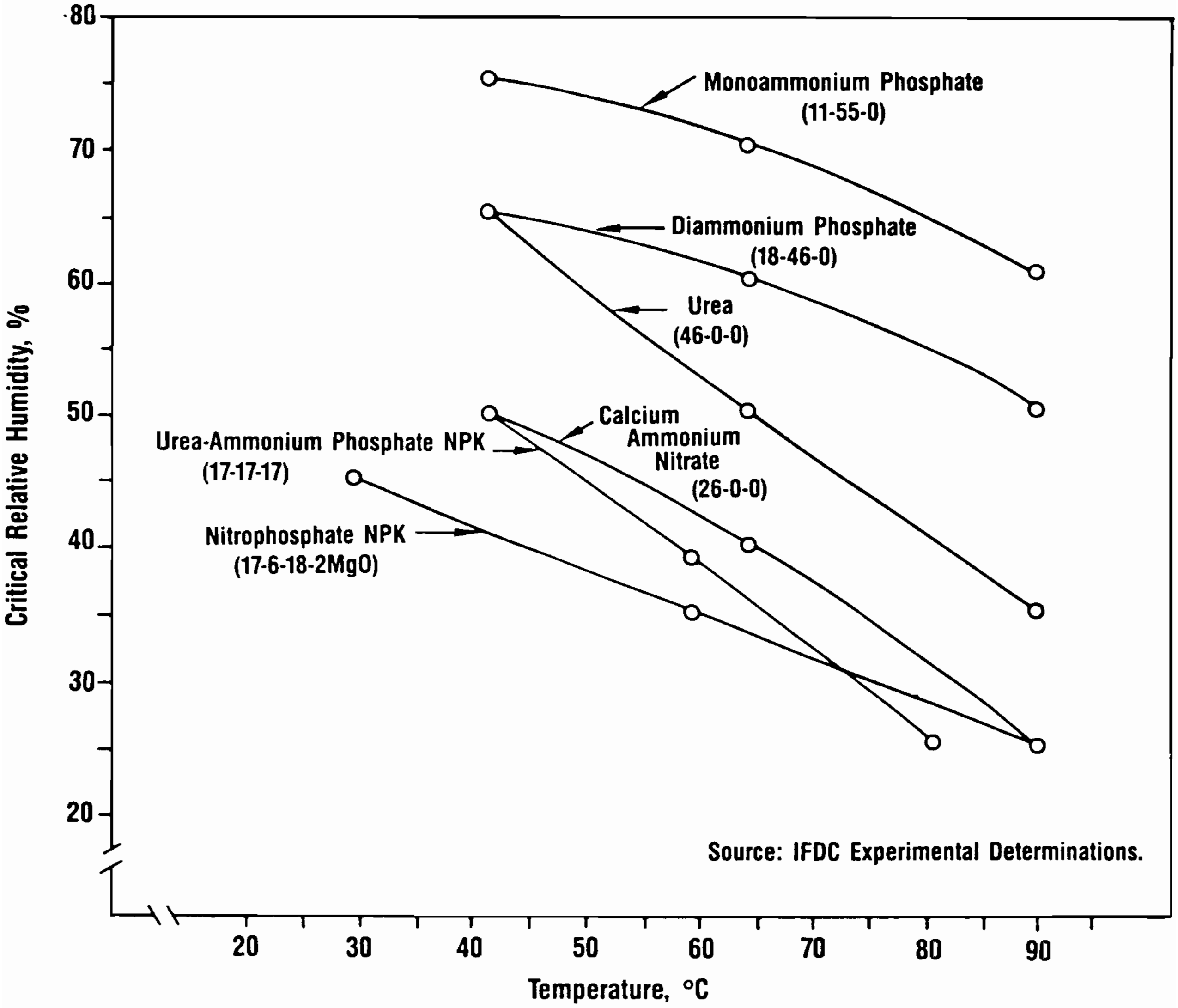
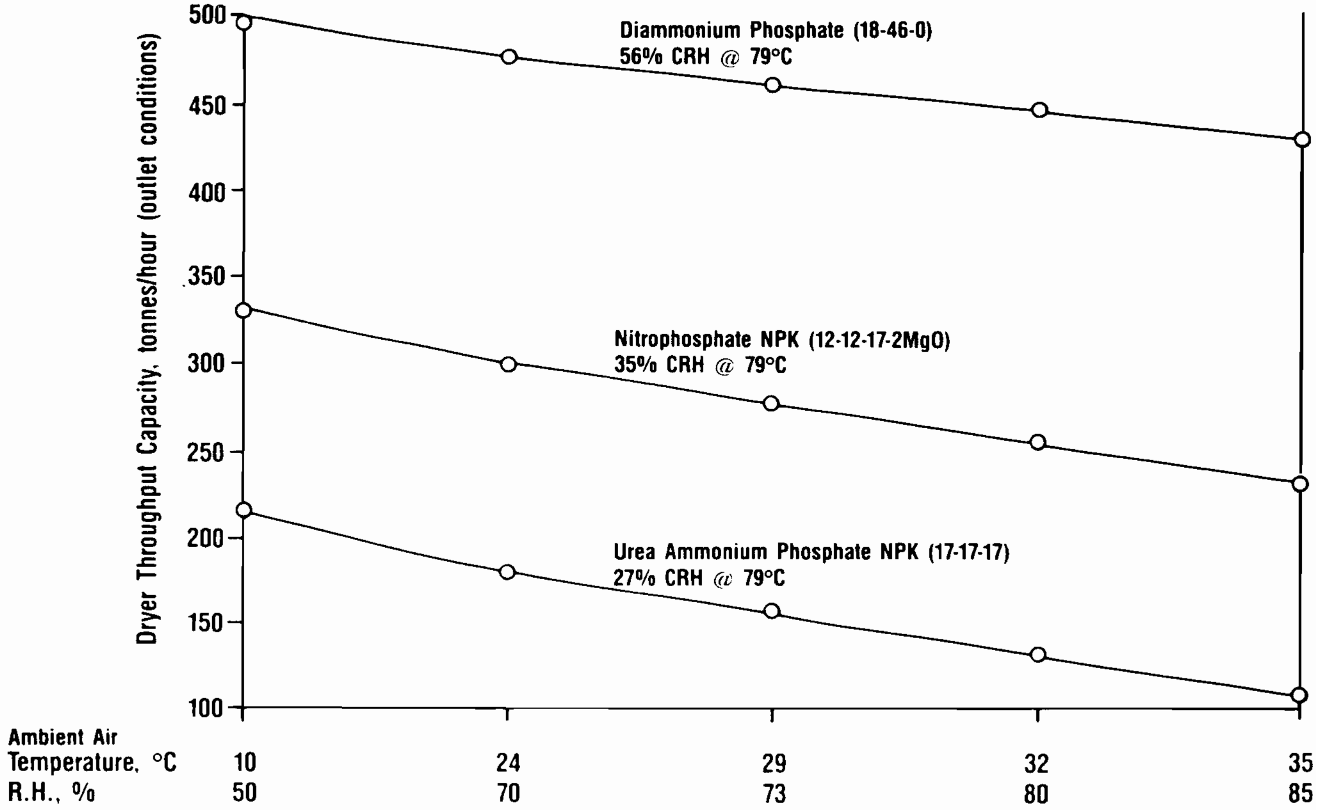


FIGURE 3. Effect of Temperature on Critical Relative Humidity of Selected Fertilizers.



Source: IFDC Experimental Determinations.

**FIGURE 4. Effect of Fertilizer CRH and Exit Air RH on Dryer Capacity.**



## DRYER OPERATING PARAMETERS

Dryer size—3.66 m diameter, 27.43 m long

Dryer superficial air velocity—2.6 m/s at outlet conditions (all grades)

| Fertilizer moisture, % | Inlet | Outlet |
|---|---|---|
| DAP | 3.5 | 1.2 |
| NPK 12-12-17-2 MgO | 2.5 | 0.7 |
| NPK 17-17-17 | 2.5 | 0.7 |

Dryer exit air temperature—82°C (all grades)

Fertilizer temperature—79°C inlet and outlet (all grades)

RH of dryer exit air—DAP: 46%, 12-12-17-2 MgO: 25%,
17-17-17: 17%

Fertilizer CRH minus RH of dryer exit air—10 percentage points
(all grades)

# Use of Urea in Blends, Liquids, and Homogenous Mixtures

*Frank P. Achorn, SE-ME, Inc.*
*and*
*Carl A. Cole, Jr.,*
*Donald L. Kachelman,*
**Tennessee Valley Authority**

## USE OF UREA IN BLENDS

Bulk blending continues to be the major marketing system for fertilizer mixtures in the United States and is becoming very popular in other nations. There are an estimated 5,000 or more bulk blending plants in the United States which produce about 17 million tons of mixtures. Eighty-two percent of blenders use urea. We estimate between 2.5 and 3.0 million tons of urea are used in blends. A typical blend plant is shown in Figure 1. Some new storage buildings are made from preformed concrete slabs. Each bin, which has concrete floors and walls, is loaded from a port in the roof above. Materials are usually removed from storage by front-end loaders. They are either weighed in a hopper scale supported above the boot of the elevator or in a retaining hooper mounted above a weight scale. With the arrangement shown in Figure 1, only one operator is required to remove materials from storage, weigh the material, blend the product, and discharge the mixer.

The percentage of bagged product is increasing. This increase is from the popularity of blends for turf, horticulture, garden and of the specialty markets. Most states have rather strict grade controls for bagged products. Therefore, segregation of ingredients in blends is even more important than ever. Blending is significantly increasing in many other countries and almost all of these products are bagged.

The major problems in the use of urea in blending are:

1. Some of the urea sold today is of particle size either too large or too small. This mismatch causes grade control problems from segregation of the ingredients.
2. Urea is not chemically compatible with other materials in the blend (i.e., triple superphosphate).
3. Combinations of urea, ammonium phosphates, and potash form mixtures which have a low critical humidity. The critical humidity (% relative humidity at which the mixture absorbs moisture from the atmosphere—CRH) of urea and diammonium phosphate (DAP) is about 50 to 60%. The CRH of urea, DAP, and potash is about 45%.

## SIZE

There is an increased emphasis on using raw materials that are closely matched in size. The size control problem is difficult for the entire industry because of the wide variance in materials from different suppliers and even between shipments from the same supplier. Also the procedures blenders use in handling materials and blending product compound the problem. Figure 2 shows a graph of material particle size (in mm × 100) that was received and used by a blender. The Size Guide Number (SGN) is a targeted value that is used to estimate material particle size. SGN is the median particle size. Observe that the SGN (50% cumulative value) of DAP from supplier A is about 270 whereas the SGN for supplier B is 215 and 260. Most blenders prefer to use materials having a SGN of 215 to 220. Ideally, the SGN's of all ingredients in a blend should match.

Size variance also occurs between suppliers of urea, potash, and other raw materials. The SGN of most prilled urea is about 145 and granular urea usually varies from 200 to 280. Some large operators that emphasize bagged products have considered purchasing prilled urea, melting it, and then granulating it to size. One granulation plant has been built and produces uniformly sized granular urea with a SGN of 210 to 220. Another granulation plant for urea conversion is under construction. Blenders of specialty fertilizers prefer SGN's of 210 to 230 because this size is easier to match with other materials. They would favor suppliers having a standard SGN for all materials, stressing, however, that SGN should not be monitored by control officials, but simply be a target number for both blenders and their suppliers. The industry should take a leadership role in helping to standardize the material size for the blending industry.

In many bulk blending plants the operator also causes segregation problems. Materials are usually stored in conical-shaped piles. This separates material by size as it is unloaded so that larger granules collect on the edge of the pile and smaller sizes remain in the center. When the operator removes materials from bulk storage, the first material removed from the pile is the largest material. As additional material is removed, the particle size becomes too small to match the size of other materials. Segregation from coning is compounded by the wide range of particles in the materials used in blends.

There are new urea processes in which urea of a narrow size range is produced. When these materials are piled in conical piles, there is essentially no separation because all of the particles are about the same size. The particle size of a closely matched DAP and urea are as follows:

**PARTICLE SIZE OF DIAMMONIUM PHOSPHATE (DAP) AND UREA OF NARROW SIZE RANGE**

| Screen Size (Tyler Screens) | Accumulative Weight, % DAP | Urea |
|---|---|---|
| 6 | 1 | <1 |
| 8 | 36 | 8 |
| 10 | 86 | 85 |
| 14 | 99 | 100 |
| 20 | 100 | 0 |
| Size Guide No. | 225 | 215 |

These materials should have a minimum of particle size and separation as they are delivered to bulk storage. When these two materials are mixed there should be essentially no segregation in the blend. However, these sizes are not typical. Therefore, the blender should minimize coning as the materials are discharged into the pile. A simple anti-coning device is shown in Figure 3. Although it does not prevent the separation of large and small particles, it does form two or more piles that overlap and prevent fines from collecting in one point. Other devices, such as an oscillating conveyor that layers material in the pile, or telescoping chutes, have been used successfully to minimize size separation from coning in bulk piles.

### *CHEMICAL COMPATIBILITY*

Tests have shown that when urea is mixed with superphosphates, the mixture becomes wet. The materials form an adduct releasing the molecular water from the superphosphate. Some blenders have found that small addition of a drying agent. Such as vermiculite or attapulgite clay, will absorb this moisture and the blend will remain free flowing.

### *CRITICAL HUMIDITY*

It is difficult to avoid forming mixtures that have low CRH's when the main ingredients used in bulk blending are urea, DAP, and potash. Mixtures of these three materials have a CRH as low as 45%. At this low value the product must be shipped in sealed bags to prevent absorption of moisture from the atmosphere. Some blenders use parting agents to minimize contact between particles and keep the blend free flowing. Blenders have shown that it is possible to produce good quality blends from urea, ammonium phosphates, and potash provided they take these precautions.

### *RECOMMENDATIONS*

1. SGN numbers for each material be agreed upon by both suppliers and blenders. A good target SGN is 215.
2. All blends that contain urea and are bagged should be contained in moisture-proof bags and conditioned with a suitable parting agent.

### *USE OF UREA IN GRANULAR HOMOGENOUS MIXTURES*

Several companies in the U.S., India, Turkey, etc., have produced granular homogenous mixtures from urea, phosphoric acid, ammonia, and potash. One of the problems in producing these products is their low melting point. Plant tests show to avoid melting the material in the granulator, the temperature in the granulator should be kept below 175°F. Most plants operate between 160 and 170°F. Concentrated phosphoric acid (54% $P_2O_5$) should be sprayed above the bed of material in the granulator, although a preneutralizer can be used to partially ammoniate the acid before spraying.

Although the use of the preneutralizer helps remove heat from the granulator, it adds water to the granulator. This is because the preneutralizer slurry must be maintained at more than 15% water to be pumped. One solution to the resulting higher recycle rates is installing a pipe-cross reactor (PCR) in the granulator. Figure 4 shows a sketch of this reactor.

Phosphoric acid (54% $P_2O_5$), ammonia, and scrubber liquor are fed to the PCR. The heat of reaction causes a low-moisture melt to be formed (<5% $H_2O$). The melt is sprayed at relatively high pressure onto the bed of material in the granulator, coating its contents. Usually lower recycle rates can be maintained. Through the use of the PCR it is possible to reduce the heat load to the bed of the granulator with a minimum addition of water.

With PCR granulation no drying is required; however, a chiller ($NH_3$ vaporizer) should be installed to cool the inlet gas stream to the cooler. This chiller will maintain the temperature in the granulator through cooler recycle. It will also improve crushing and screen efficiency as well as the storage characteristics of the product.

Most N:P and N:P:K urea mixtures have CRH of 45 to 55%. For this reason it is recommended that these materials be stored in dehumidified buildings. The material should be conditioned (2% clay) and bagged in moisture-proof bags; these products should not be sold in bulk.

### *UREA IN FLUIDS*

Why use solid urea to produce fluids when, except for potash, all of the other materials are in the fluid form? The most important reason is cost. Urea is frequently less expensive than nitrogen solution (UAN). Figure 5 shows a comparison of the nitrogen fertilizer prices. These data show that in the past 5 years the price of nitrogen in urea is often substantially less than in nitrogen solution. During these times using larger quantities of urea in solutions can result in significant savings. One way to take advantage is to use urea as a supplement to UAN (28-32% N) to reduce the overall cost. Figure 6 shows the solubility system of urea, ammonium nitrate, and water. It also shows the temperature isotherms for various mixtures of ammonium nitrate and urea. These data show a 32% N nitrogen solution (UAN) that contains 44% ammonium nitrate and 35% urea has a salt-out temperature of 32°F. This solution contains about 51% of its nitrogen as urea. The same solubility system shows a 28% N solution having 64% of its nitrogen as urea. This solution can be produced from the 32-0-0 plus urea and water and have the same salt-out temperature of 32°F. Therefore, when the unit cost of N from urea is less than from UAN, this is a good way to lower the overall material cost of N in solutions.

Many suspension fertilizer producers add supplemental nitrogen to a base N-P grade as 10-30-0. This nitrogen is usually supplied by UAN solution. Many operators also have problems with large crystal formation in their N-P base grades from inadequate cooling. Using urea as a source of supplemental N allows the operator to take advantage of decreased nitrogen costs while urea's negative heat solution quenches the suspension product. Satisfactory 18-18-0 grades have been produced from MAP, ammonia, and urea.

Urea has also been used effectively to produce acid-type solutions. These materials are effective carriers of micronutrients. Some are high analysis with pH values less than 1.0. Typical grades produced from urea, water, UAN solution, potash, phosphoric acid and/or sulfuric acid are: 27-9-0, 6-18-0, 9-0-0-25S, 11-8-8, 6-30-6, and 16-11-5.

TVA has demonstrated that urea can be used successfully to produce and market a 36% nitrogen suspension that contains 72.2% urea and only 27.8% ammonium nitrate. Therefore, this suspension should be more economical to produce and deliver than standard UAN solution (28 to 32% N). The 36-0-0 works well in producing mixtures that are high in analysis. It is usually mixed with a phosphate base suspension that is produced from MAP (usually a 10-30-0 grade) and potash. Some typical grades are 14-14-14, 7-21-21, 10-20-10, 20-5-5, etc. Some researchers have also found one way to reduce the sludge which forms in phosphoric acid is urea addition before storage.

## *CONCLUSION*

Urea is an economical and versatile source of nitrogen. It has been used effectively to produce blends, homogenous mixtures, and fluid fertilizers. Some of our economists estimate that about 60% of the current capacity is used. Numerous urea plants are now being constructed throughout the world. It is believed that with the exception of ammonia, urea will be the most economical source of nitrogen for several years. For this reason, we must learn how to successfully use it.

**FIGURE 1 BULK BLEND PLANT WITH CONCRETE-TYPE MIXER**

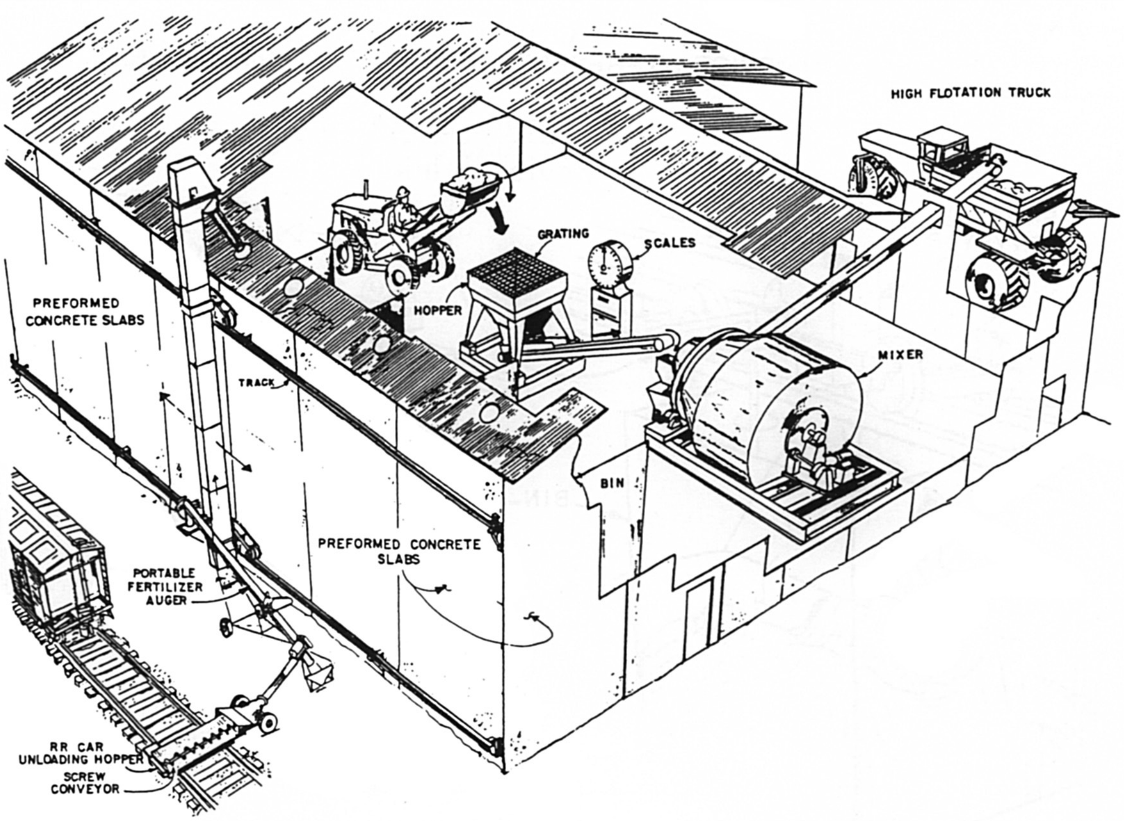


FIGURE 2

Particle Size (mmx100) of DAP
Versus
Accumulative Percent Retained on Screens

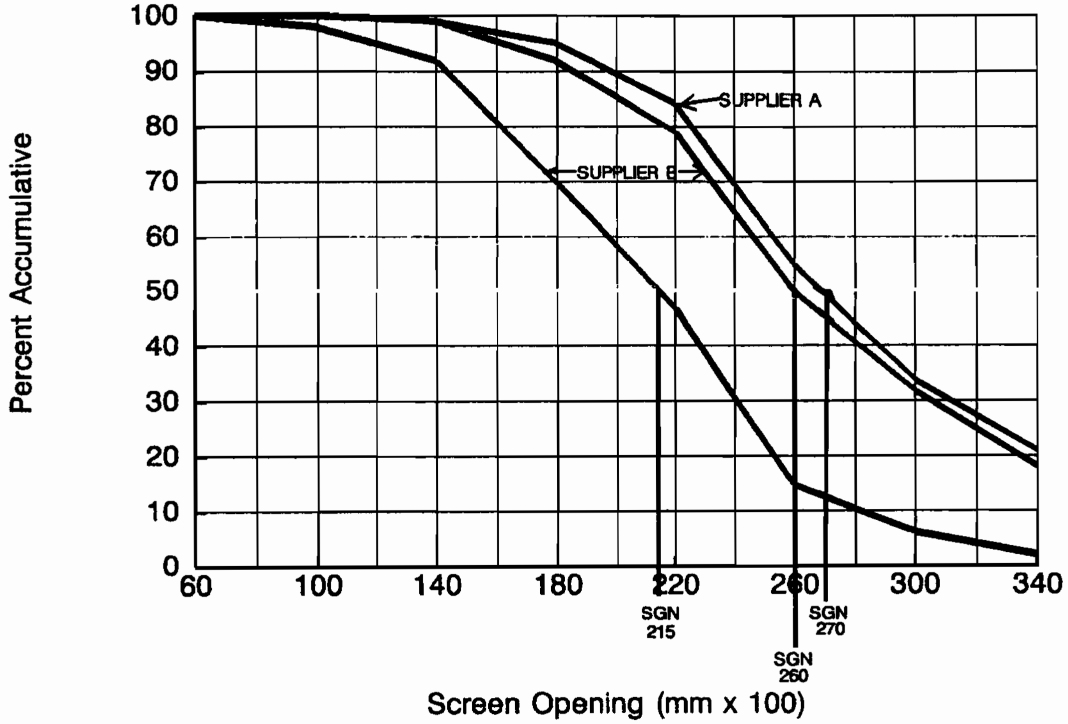
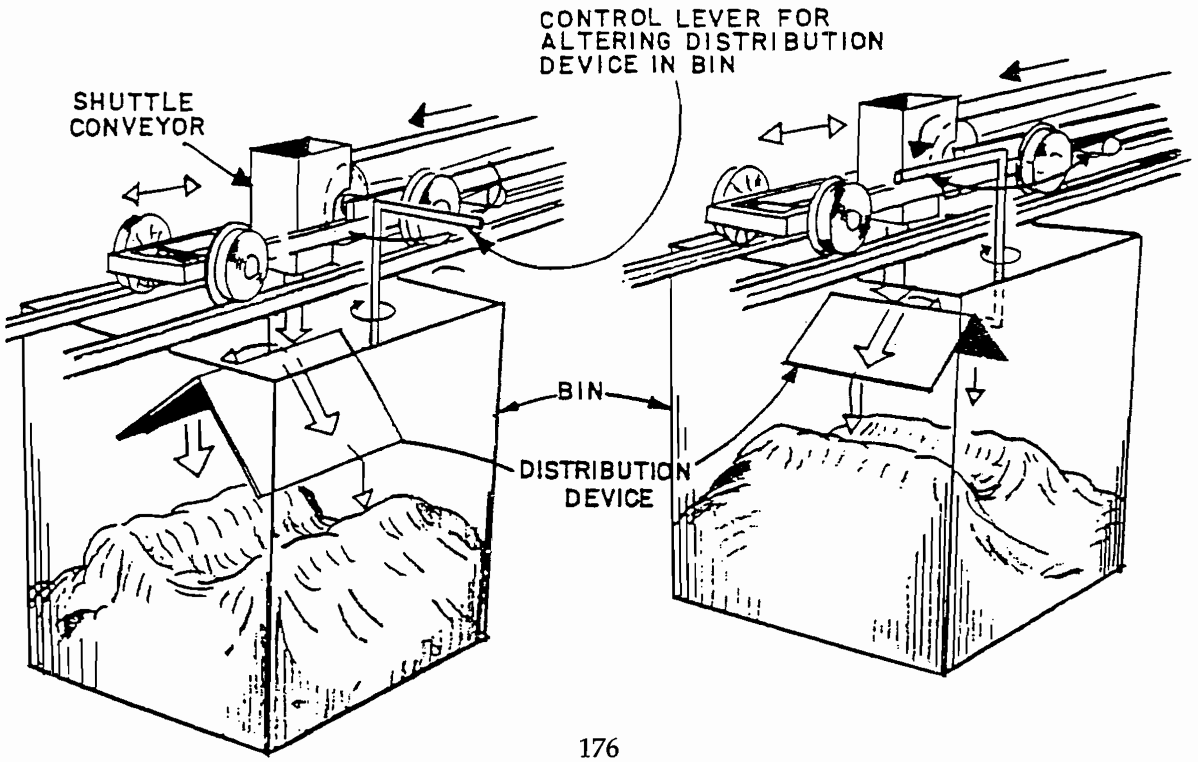
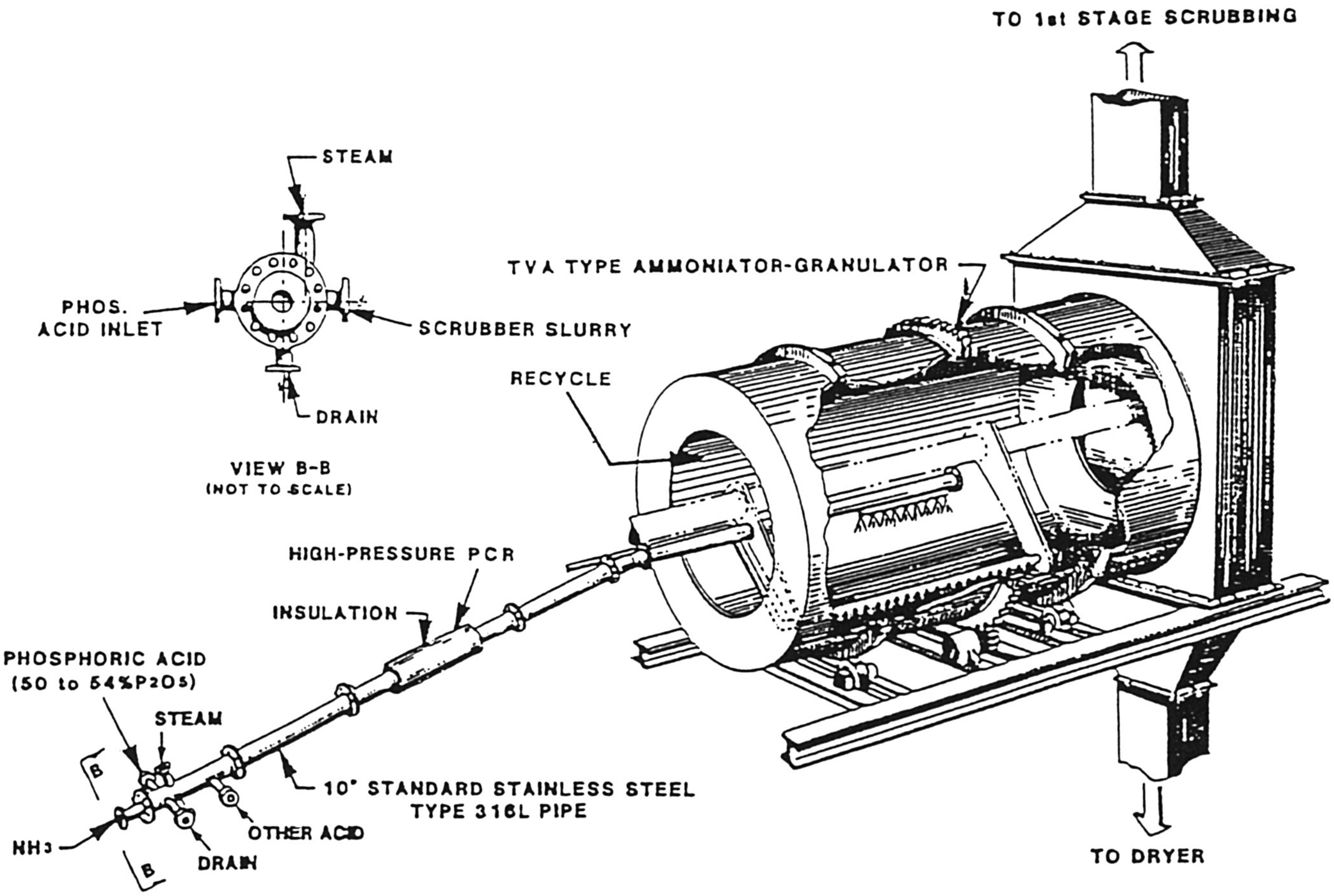


FIGURE 3
DISTRIBUTION DEVICE TO PREVENT CONING OF MATERIAL IN BINS

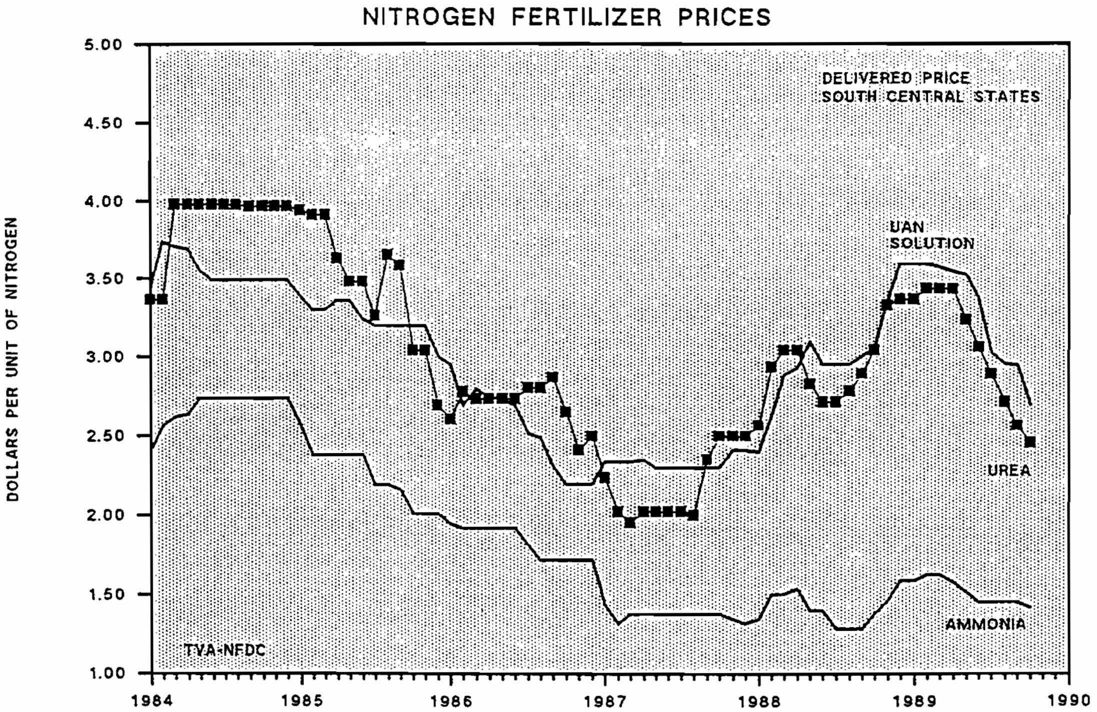


## FIGURE 4

## TVA HIGH-PRESSURE PIPE-CROSS REACTOR FOR GRANULATOR OF MAP-DAP COMMERCIAL PLANT

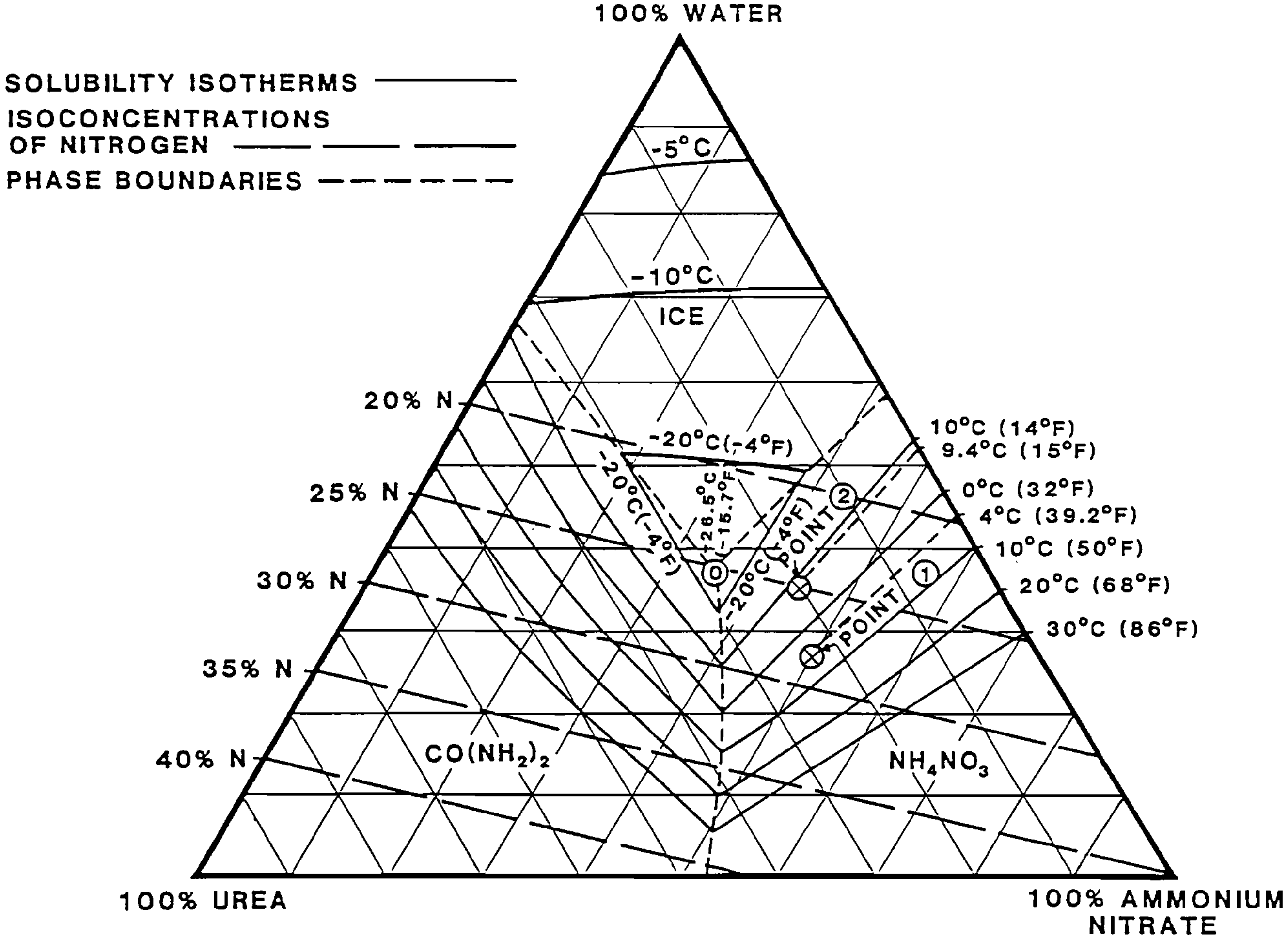


## FIGURE 5



# FIGURE 6

## SOLUBILITY SYSTEM OF AMMONIUM NITRATE-UREA-WATER



# FINANCIAL STATEMENT

*November 10,1988 to October 25, 1989*

| | | |
|---|---|---|
| Cash Balance November 10, 1989 | | $22,613.20 |
| **Income November 10, 1988 to October 25, 1989** | | |
| Registration Fees—1988 Meeting & Cocktail Party Receipts | $ 5,670.00 | |
| Sale of Proceedings | 2,126.59 | |
| Registration Fees - 1989 Meeting & Cocktail Party Receipts | 12,515.00 | |
| Total Receipts November 10, 1988 to October 25, 1989 | | 20,311.59 |
| Total Funds Available November 10, 1988 to October 25, 1989 | | $42,924.79 |
| **Disbursements November 10, 1988 to October 25, 1989** | | |
| 1988 Meeting Expenses (Incl. Cocktail Party) | $ 7,364.37 | |
| Misc. Expenses Incl. Postage, Stationery, etc. | 403.86 | |
| Directors Meetings | 1,424.52 | |
| 1988 Proceedings Incl. Printing, Postage, etc. | 11,576.83 | |
| Advertising | 736.00 | |
| 1989 Meeting—Prel. Expenses | 885.72 | |
| Total Disbursements November 10, 1988 to October 25, 1989 | | $22,391.30 |
| CASH BALANCE—October 25, 1989 | | $20,533.49 |

Respectfully submitted,

PAUL J. PROSSER, JR.
Secretary/Treasurer

Meeting Attendance: 139