World Fertilizer Nutrient Reserves— A View to the Future

By Paul E. Fixen

The stewardship responsibilities of agriculture include the wise use of the raw materials from which commercial fertilizers are produced. Development and implementation of fertilizer best management practices (BMPs) with focus on the 4Rs—right source, right rate, right time, right place—are timely not only for short-term economic and environmental reasons, but also for the wise stewardship of the non-renewable nutrient resources upon which food, feed, fiber, and fuel production depend.

The extreme spike in N, P, K, and S fertilizer prices midway through 2008 sent shock waves around the world. Some pondered whether fertilizer nutrient reserves were reaching critically low levels and contributing to market volatility. This paper will attempt to review the status of world nutrient reserves in terms of current production.

Phosphate

The main raw material used in the production of nearly all phosphate fertilizers is phosphate rock (PR). There are two general types of PRs, igneous and sedimentary. Insular or island deposits are a special type of sedimentary deposits. **Figure 1** shows a map of PR deposits currently being mined, those that have been mined in the recent past, and those that have been shown to be potentially economic (McClellan and Van Kauwenbergh, 2004). They are widespread throughout most of the world.

Figure 1. Economic and potentially economic phosphate deposits of the world (Source: S.J. Van Kauwenbergh, IFDC).

Igneous PRs typically contain apatite as the P form along with other igneous minerals. Igneous deposits often yield low grade ores, but can be beneficiated to higher grades in the range of 36 to 40% P_2O_5 (Stewart et al., 2005). Ores from igneous deposits are relatively unreactive. Consequently, they are not well suited for direct application to cropland and typically must be finely ground for use in fertilizer processing.

About 80% of the PR produced in the world is from sedimentary deposits. These deposits vary markedly in both physical and chemical properties, ranging from loose, unconsolidated materials to hardened rocks and from fluorapatite with almost no carbonate substitution to 6 to 7% carbonate for phosphate substitution (Stewart et al., 2005).

World PR production since 1981 has been generally rather flat overall, ranging from 120 to 165 million metric tons (M t) per year (**Figure 2**). However, the breakup of the Soviet Union caused a substantial disruption in phosphate production, resulting in major declines in the early 1990s. World production has just recently climbed back up to pre-breakup levels exceeding 160 M t. China has been the major source of production increases during the last 20 years.

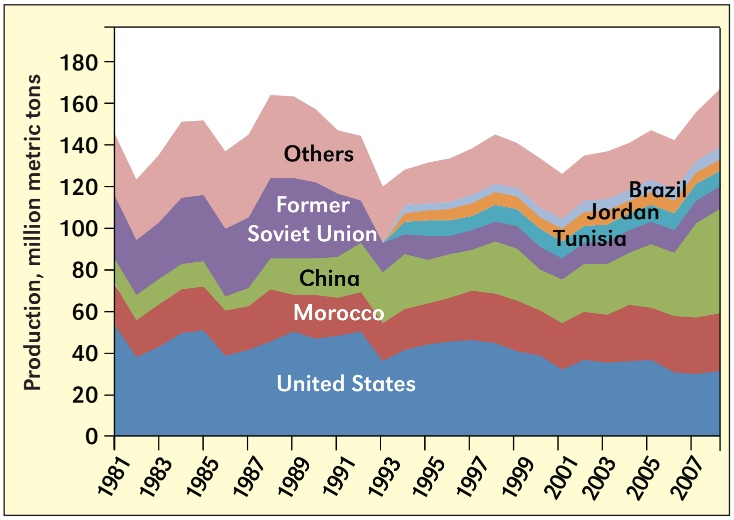

Figure 2. World phosphate rock production, 1981-2008.

[1] 1992-1997 FSU includes Kazakhstan and Russia data; afterwards, Russia only.

[2] Compiled from USGS Mineral Commodities Reports, 1983-2009. Year 2008 estimated.

Estimation of PR reserves and resources is plagued with uncertainty due to limited information to assure accuracy of the estimates. Phosphate producers often consider reserve information to be confidential, leaving publicly available scientific papers and specific deposit reports as the primary information sources. Therefore, the reserve information presented here needs to be viewed as general approximations with broad confidence intervals.

Table 1 contains current estimates of world PR reserves and reserve base sorted by reserve base tonnage. Reserves and reserve base terms are defined by the U.S. Geological Survey (USGS) as follows. "Reserves – that part of the reserve base which could be economically extracted or produced at the time of determination. The term reserves need not signify that extraction facilities are in place and operative. Reserve base – includes those resources that are currently economic

Abbreviations and notes: BMPs = best management practices; N = nitrogen; P = phosphorus; K = potassium; S = sulfur.

(reserves), marginally economic, and some of those that are currently subeconomic."

However, personal communication with USGS indicated that current reserve estimates are based on market conditions from at least a few years ago and so do not reflect 2008 prices. Therefore, the portion of reserve base tonnage reported as reserves may be underestimated.

Morocco and Western Sahara are reported to have the largest PR reserve base and reserves in the world accounting for 45% of the world reserve base (**Table 1**). China follows with 21% of the reserve base, so these two countries have two-thirds of the world RP reserve base. **Table 1** also contains estimates of PR reserve life and reserve base life based on the average production of 2007 and 2008. At these production levels, world PR reserve and reserve base longevity would be estimated to be 93 and 291 years, respectively.

At this point, it is critical to remember the earlier comments about the reliability of these estimates. Two examples illustrate this point. First, in 2002, USGS was estimating PR world reserves and reserve base at 12,990 and 46,990 M t respectively (Stewart et al., 2005). The 2009 estimates discussed above represent 122% and 100% of these earlier estimates, even though an additional 7 years of production has occurred since they were made. As a second example, Sheldon (1987) reported world PR reserves at 15,259 M t (about the same as is being estimated today) and identified resources (reserve base plus inferred reserve base) as 112,431 M t. These identified resources based on today's production would amount to longevity of 696 years.

Table 1. Phosphate mine production, reserves, and reserve base.

	Mine production[1] 2007	2008[2]	Reserves[3]	Reserve base[4]	Reserve life[5]	Reserve base life[5]
Country	- - - - - - - - - Million metric tons - - - - - - - - - -				- - - -Years - - - -	
Morocco & W. Sahara	27.00	28.00	5,700	21,000	207	764
China	45.40	50.00	4,100	10,000	86	210
United States	29.70	30.90	1,200	3,400	40	112
S. Africa	2.56	2.40	1,500	2,500	605	1,008
Jordan	5.54	5.50	900	1,700	163	308
Australia	2.20	2.30	82	1,200	36	533
Russia	11.00	11.00	200	1,000	18	91
Israel	3.10	3.10	180	800	58	258
Syria	3.70	3.70	100	800	27	216
Egypt	2.20	3.00	100	760	38	292
Tunisia	7.80	7.80	100	600	13	77
Brazil	6.00	6.00	260	370	43	62
Canada	0.70	0.80	25	200	33	267
Senegal	0.60	0.60	50	160	83	267
Togo	0.80	0.80	30	60	38	75
Others	8.11	10.80	890	2,200	94	233
World total	156	167	15,000	47,000	93	291

[1] P_2O_5 content varies from 23 to 39% P_2O_5 with an average in 2007 of 32%. U.S. rock averages 29%. [2] Estimated. [3] Reserves can be economically mined at the time of determination. [4] Reserve base includes economic, marginally economic, and some currently subeconomic resources. [5] Life based on 2007-2008 production. Source: U.S. Geological Survey, 2009c.

Clearly, great uncertainty exists in these estimates. And just as clearly, the world is not on the verge of running out of raw materials for phosphate fertilizer production. That said, these are non-renewable natural resources and deserve our very best stewardship.

Potash

Potash refers to a variety of K-bearing minerals with the most common ones being sylvite (KCl), sylvinite (KCl+NaCl), hartsalz (ore deposits with sulfate salts), and langbeinite ($K_2SO_4 \bullet 2MgSO_4$). Economic sources occur in sedimentary salt beds remaining from ancient inland seas (evaporate deposits) or in salt lakes and natural brines. The general locations of potash reserves and reserve base are shown in **Figure 3**. The world's largest reserves occur in Saskatchewan, Canada, where the ore is exceptionally high grade (25 to 30% K_2O) and occurs at depths of 1,000 meters up to greater than 3,500 meters. These deposits are mostly sylvinite, with some carnallite ($KCl \bullet MgCl_2 \bullet 6H_2O$), and clay.

Production, reserves, reserve life, and longevity based on USGS data are reported by country in **Table 2**. Canada has 53% of world potash reserves while Canada, Russia, Belarus, and Germany collectively have 92%. World potash reserves are huge, with a reported reserve life based on current production of 235 years and a reserve base exceeding 500 years.

New production of about 1 M t K_2O capacity is expected to be added per year from 2009 through 2011, mostly by Canada, Russia, and Israel, with some from Jordan and the USA. An additional 5 M t is expected in 2012 by Canada, Argentina, Belarus, and Jordan (Prud'homme, 2008). New production through 2012 would total to approximately 8 M t.

Sulfur

Sulfur is one of the more common constituents of the Earth's crust. USGS estimates resources of elemental S in evaporite and volcanic deposits and S associated with natural gas, petroleum, tar sands, and metal sulfides at about 5 billion tons. The S in gypsum and anhydrite is almost limitless, and some 600 billion tons of S is contained in coal, oil shale, and shale rich in organic matter, but low-cost methods have not been developed to recover S from these sources (USGS, 2009e). However, S is not generally produced intentionally as a primary product. Most of the S available on the world market today is extracted from natural gas and oil as crude oil contains from 0.1 to 2.8% S (IFDC, 2008). Some S is also recovered from coal, the roasting of sulfides in metallurgical processing, and by mining of pyrites.

About 80 to 85% of the world's S production is used to manufacture sulfuric acid. Half of the world's sulfuric acid production is used in fertilizer production, mainly to convert phosphates to water-soluble forms. About 1 ton of S is needed to produce a little more than 2 tons of diammonium phosphate (DAP) (IFDC, 2008).

The leading countries in S production are the USA, Canada, China, and Russia. These four countries produce almost half of the world's S. Because petroleum and sulfide ores can be processed long distances from where they are produced, USGS

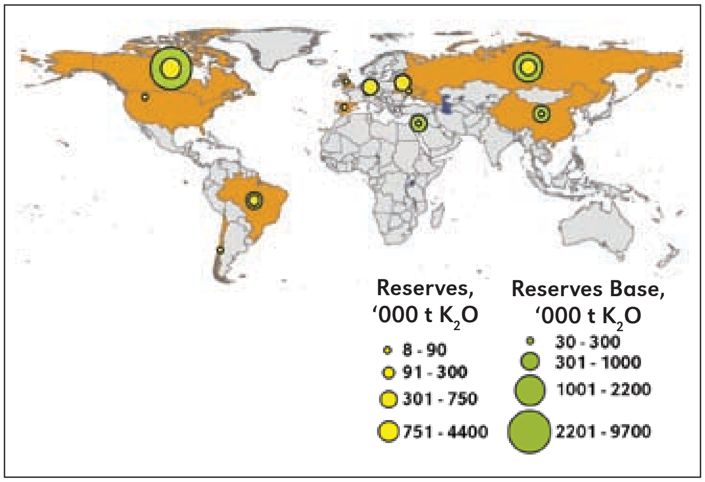

Figure 3. Potash reserves and reserve base (Source: U.S. Geological Survey, Mineral Commodity Summaries and Potash, January, 2008).

points out that actual S production may not be in the country for which reserves are attributed. This is one of the reasons that reserves and reserve base data are not reported by country for S. Gypsum ($CaSO_4 \cdot 2H_2O$) production is reported by country. A small amount of this product is used for agricultural purposes as a soil conditioner and a nutrient source. As an example, a little over 1 M t of the 12.7 M t of gypsum produced in the USA in 2008 was used in agriculture. In the long-term, the increase in world S supply is expected to overcome spot shortages as occurred in mid-2008 when S prices skyrocketed from less than \$100/ton to over \$800/ton. The price spike was driven by tight supplies resulting from lower than expected production in the USA and slow progress at new petroleum and natural gas developments coupled with increased consumption at phosphate fertilizer operations. A sharp decline in S demand in Asia in the third quarter of 2008 drove the price crash that occurred late in the year.

Table 2. Potash mine production, reserves, and reserve base.

	Mine production 2007	Mine production 2008[1]	Reserves[2]	Reserve base[3]	Reserve life[4]	Reserve base life[4]
Country	- - -Million metric tons K_2O equivalent - - -				- - - -Years - - - -	
Canada	11.10	11.00	4,400	11,000	398	995
Russia	6.60	6.90	1,800	2,200	267	326
Belarus	4.97	5.10	750	1,000	149	199
Germany	3.60	3.60	710	850	197	236
Brazil	0.41	0.43	300	600	719	1,437
Israel	2.20	2.40	40	580	17	252
Jordan	1.09	1.20	40	580	35	507
China	2.00	2.10	8	450	4	220
United States	1.10	1.20	90	300	78	261
Chile	0.50	0.58	10	50	19	93
Spain	0.58	0.59	20	35	34	60
Ukraine	0.01	0.01	25	30	2,083	2,500
United Kingdom	0.43	0.48	22	30	49	66
Other			50	140		
World total	34.6	36.0	8,300	18,000	235	510

[1] Estimated. [2] Reserves can be economically mined at the time of determination.

[3] Reserve base includes economic, marginally economic, and some currently subeconomic resources.

[4] Life based on 2007-2008 production. Source: U.S. Geological Survey, 2009d.

Nitrogen

Ammonia (NH_3) is the basic N source used in the manufacture of most N fertilizers. About 3% is used in direct application to crop land, mostly in North America. Non-fertilizer use accounts for about 16% of world NH_3 production (Abram and Forster, 2005). China, India, Russia, and the USA account for over 50% of total current NH_3 production, with China alone contributing nearly one-third of total production (**Table 3**).

Natural gas (CH_4) is the feedstock used in 75 to 80% of ammonia manufacturing (Abram and Forster, 2005) worldwide with about 1,230 cubic meters of gas required per ton of ammonia N (Huang, 2007). However, NH_3 manufacturing is a very small consumer of natural gas in most countries. Even if one assumes that all NH_3 is produced from natural gas, 5% of annual world gas consumption would be used for NH_3 production. In the USA, only about 1.5% of natural gas goes to NH_3 synthesis.

Thus, natural gas prices are generally independent of fertilizer markets, but greatly influence where fertilizers are manufactured. Rising natural gas prices in developed countries are causing a shift of N production to developing countries. Several companies have announced plans to build new ammonia plants in Algeria, China, Libya, and Peru (USGS, 2009b).

The topic of reserves for N fertilizers, considering the dominant manufacturing processes in use today, essentially becomes a discussion of natural gas reserves. Gas consumption and reserves sorted by reserve quantity are reported in **Table 3**. Russia, Iran, and Qatar have 57% of proven world gas reserves. Globally, we are consuming about 3.2 trillion cubic meters of gas per year and report 175 trillion cubic meters of proven reserves, giving longevity of 55 years. However, world natural gas reserves have generally trended upward, indicating that thus far producers have been able to continue replenishing reserves with new resources over time (Energy Information Administration, 2008). The largest recent additions to natural gas reserve estimates were reported for Venezuela and Saudi Arabia.

Summary

World reserves and resources for N, P, K, and S appear adequate for the foreseeable future. However, nutrient costs will likely rise over time as the most easily extracted materials are consumed. Therefore, an added incentive for continued refinement and implementation of fertilizer BMPs is that the resulting gain in efficiency will slow the increase in fertilizer costs. Wise stewardship of non-renewable nutrient resources is a critical responsibility for the agriculture industry. BC

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Table 3. Ammonia production and natural gas consumption and reserves.

Ammonia production, million metric tons N			Natural gas, cubic meters (January 1, 2008)			
				Consumption	Reserves[2]	
Country	2007	2008[1]	Country	Billion	Trillion	Total, %
China	42.48	44.60	Russia	610	47.57	27.2
India	11.00	11.00	Iran	112	26.84	15.3
Russia	10.50	11.00	Qatar	21	25.63	14.6
United States	8.84	8.24	Saudi Arabia	76	7.16	4.1
Trinidad and Tobago	5.10	5.10	United Arab Emirates	43	6.06	3.5
Indonesia	4.40	4.40	United States	653	5.97	3.4
Ukraine	4.20	4.20	Nigeria	13	5.21	3.0
Canada	4.10	4.10	Venezuela	27	4.70	2.7
Germany	2.75	2.80	Algeria	26	4.50	2.6
Saudi Arabia	2.60	2.60	Iraq	2	3.17	1.8
Pakistan	2.25	2.25	Turkmenistan	19	2.83	1.6
Iran	2.00	2.00	Kazakhstan	31	2.83	1.6
Egypt	1.75	1.90	Indonesia	23	2.66	1.5
Poland	1.90	1.90	Malaysia	33	2.35	1.3
Netherlands	1.80	1.80	China	71	2.27	1.3
Qatar	1.80	1.80	Norway	7	2.24	1.3
Japan	1.09	1.36	Uzbekistan	51	1.84	1.1
Bangladesh	1.30	1.30	Egypt	32	1.67	0.9
Romania	1.30	1.30	Canada	93	1.64	0.9
			Kuwait	13	1.59	0.9
			Libya	6	1.40	0.8
			Netherlands	46	1.40	0.8
			Ukraine	85	1.10	0.6
			India	42	1.10	0.6
			Azerbaijan	10	0.85	0.5
			Australia	29	0.85	0.5
			Oman	11	0.85	0.5
			Pakistan	31	0.79	0.5
			Bolivia	3	0.75	0.4
			Trinidad & Tobago	21	0.53	0.3
			Yemen	0	0.48	0.3
			Argentina	44	0.45	0.3
			United Kingdom	91	0.41	0.2
			Mexico	68	0.39	0.2
			Brunei	4	0.39	0.2
			Brazil	20	0.35	0.2
			Peru	2	0.34	0.2
Other countries	20.30	22.00	Other countries	727	3.83	2.2
World total	131.5	135.7	World total	3,196	175	100

[1] Estimated. [2] Reserves can be recovered under present technology and prices.

Sources: Ammonia = U.S. Geological Survey, 2009b; Gas = *Oil and Gas Journal*, 2007; NationMaster.com.

Note: Production of a ton of ammonia N requires 1,230 cubic meters of natural gas.

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