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Potash Case Study

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1 Introduction

Potash and Potassium

Potassium (K) is essential for plant and animal life wherein it has many vital nutritional roles. In plants, potassium and nitrogen are the two elements required in greatest amounts, while in animals and humans potassium is the third most abundant element, after calcium and phosphorus. Without sufficient plant and animal intake of potassium, life as we know it would cease. Human and other animals atop the food chain depend upon plants for much of their nutritional needs. Many soils lack sufficient quantities of available potassium for satisfactory yield and quality of crops. For this reason available soil potassium levels are commonly supplemented by potash fertilization to improve the potassium nutrition of plants, particularly for sustaining production of high yielding crop species and varieties in modern agricultural systems. Thus, potash, the fertilizer trade term referring to fertilizer materials containing potassium, has become an increasingly important input for satisfying demands of an expanding population for food, fibre and other commodities.

Approximately 95 % of current global consumption of potassium is used for fertilizers; the remainder is used in various industrial applications including the manufacture of caustic potassium and other intermediate chemicals. Potassium chloride or muriate of potash (MOP) is the most popular potassium fertilizer. Potassium sulphate (SOP) is the next most important potassium source followed by potassium magnesium sulphate, potassium nitrate, potassium phosphate, and solutions of potassium thiosulphate and potassium polysulphide. Other potassium containing salts such as potassium carbonate, potassium bicarbonate, and potassium hydroxide have limited use for the production of high-purity fertilizers for foliar application and other specialty uses.

Potassium Containing Minerals

Potassium is present in igneous, sedimentary, and metamorphic rocks but commercial recovery is mainly restricted to two types of sedimentary deposits, deeply buried marine evaporite deposits at depths typically ranging from 400 metres (m) to greater than 1000 m below the surface, and surface brine deposits associated with saline water bodies such as the

Dead Sea, the Great Salt Lake and China's Qarhan Lake. Sylvite, sylvinite, langbeinite, kainite, and carnallite are the minerals of greatest economic importance. Sylvinite, a mixture of potassium and sodium chloride crystals, is the easiest to process; thus it is mined and refined in the greatest quantities to extract potassium chloride (MOP).

2 Global Resources and Potash Production

World resources of potassium bearing sedimentary deposits are immense and are reported to total 17 billion tonnes (Bt) (US Geological Survey, 2001). Of this total, 8.4 Bt of K_2O reserves are categorized as commercially exploitable. With current global consumption of about 25.8 million tonnes (Mt) of K_2O annually, both economical reserves and resource bases are sufficient to meet world demand for centuries. (Details in appendix A).

Potash mining and processing

Potash ores in solid beds at depths no greater than 1400 m below the earth's surface are extracted mainly by conventional mechanized underground mining methods. Variations of room and pillar, long-wall, cut and fill, and open stope techniques are commonly used. Solution mining is employed when underground extraction is no longer feasible because of depth to deposits and/or when water inflow problems interfere with conventional underground mining. Solar evaporation of brines that naturally contain potassium is the third method of obtaining potash ore. The steps in the processing of potash ore are usually size reduction-desliming-separation-drying, then compaction or granulation.

Environmental Considerations in Potash Mining and Processing

Potash mining activities may affect the quality of air, water, and land. The beneficiation of potash ores normally results in large volumes of waste materials including brines, slimes containing clay, and salt tailings.

The disposal methods most frequently used include:

- Stacking of salt tailings on the surface.
- Retention of wastes such as brines and slimes in dams or ponds.
- Controlled release of wastes from lined retention ponds into rivers and oceans.
- Backfilling of mined underground openings with salt tailings and fines.
- Deep well injection of brines.
- Recovery of other mineral by-products

The methods are constantly being refined to minimize their environmental impacts.

World Potash Supply and Demand Balance

World production of potassium fertilizer salts has grown significantly in the last century to meet the growing requirements for plant nutrition. In the period 1998 to 2001, potash production varied in the narrow range of 25.4 to 25.8 Mt yearly compared to consumption of between 21.9 and 22.8 Mt.

World Potash production (K2O equivalent)

1900	1950	1955	1960	1980-1990	1998-2001
0.2 Mt	3.3 Mt	7.2 Mt	9.1 Mt	24.4-31.9 Mt	25.4-25.8 Mt

The world potash market is characterized by a limited number of producers (14), supplying high-concentration products in all regions. Four countries account for three-quarters of global output: Canada, Russia, Germany and Belarus. World annual production ranges between 25 and 26 Mt K_2O, with a 2-3 % annual growth rate. Global K_2O fertilizer production capacity in 2001 and that projected for subsequent years to 2005 lies within a narrow range of 37.4 to 38.3 Mt/a.

In 1998 and 1999, potash usage of between 11.1 to 11.4 Mt in developed countries was only slightly more than consumption of 10.5 to 10.9 Mt annually in developing countries. In the following two years, developing countries consumed 11.3 to 11.8 Mt contrasted with slightly lower usage of 10.6 to 11.1 Mt in developed countries and this pattern is expected to continue into the foreseeable future. Major consuming regions, such as Asia and Latin America, will continue to depend substantially on imports, due to the resilient imbalance in the supply/demand situation, and the sustained growth in demand. Exporting regions such as North America, East Europe/Central Asia and the Near East will expand their capabilities to meet world requirements for potash in growing and emerging markets.

For the next five years, the global potash capacity will continue to expand, reaching 38.3 Mt K_2O in 2005, a net addition of 1.4 Mt K_2O (or 0.7%/a) over 2000. Potash demand is expected to grow at an annual rate of 2.6%, to reach close to 28.4 Mt/a K_2O. World fertilizer potash demand is forecast to reach 25 Mt by 2005. The current surplus of production capacity will gradually decline in the next five years, but will still remain at a fairly substantial level.

3 The use of potassium in fertilizer

3.1 Potassium Fertilizer Consumption

Four countries currently account for close to 53% of global potash usage. The United States is the largest of these consumers typically accounting for about 20% of global usage. China, Brazil, and India represent approximately 15%, 10%, and 7%, respectively of world consumption. Western Europe (France, Germany, Italy, Spain, and the United Kingdom) is also an important consuming region, amounting to about 17.5% of the world's total in recent years.

Factors influencing potassium fertilizer consumption

Demand for potassium fertilizers depends upon a number of factors including:

- extent and severity of potassium deficiency in cropland;
- introduction of new or improved crop varieties with greater potassium requirements;
- shifts in demand for agricultural commodities;
- profitability of potassium fertilization to farmers; prices for commodities and other fertilizers;
- government crop production/restriction programs; and,
- weather conditions.

Effects of cropping on removal of soil potassium

Potassium increases plant resistance to drought, frost and to a number of diseases and pests, it is essential for the development of the root system and fosters nitrogen fixation of leguminous crops, and it improves the size, colour and sugar content of crops such as fruits. Natural reserves of soil potassium diminish with each successive crop. This withdrawal or "soil mining" is greatly increased and accelerated by higher yields and more intensive cropping. For example, high-yielding, short-season rice varieties in a double cropping system will remove up to 36 times more potassium from soil compared to a single crop of traditional varieties. Potassium uptake by rice in a triple cropping system will be about 50% more than by two crops annually. Although some soils are rich in potassium, many are poorly endowed and crop production thereon is unsustainable if potassium removed by cropping is not replenished in appropriate amounts.

Benefits of potassium in balanced fertilization

Sound soil fertility management involves the use of potassium in proper relationship to inputs of the other macronutrients such as nitrogen (N), phosphorous (P) and sulphur (S). The concept of integrated plant nutrient management integrates all other production factors in order to maintain soil fertility and productivity, to prevent land degradation and desertification, to alleviate soil nutrient mining and prevent erosion. Without adequate potassium, the full potential benefits of investments in the other major fertilizer nutrients and the other essential crop production inputs such as water are at risk. Potassium encourages more efficient nutrient utilization by plants, which in turn contributes to economic viability, improved ecological conditions and sustainable agriculture.
Major potassium fertilizer products

Abundance of supply, high nutrient content and competitive pricing are the main reasons responsible for the dominance of potassium chloride (MOP) as a source of potassium. Additionally its content of chloride, another essential plant nutrient, is beneficial for several crops, notably coconut and oil palm. Chloride often is beneficial for increased resistance to pests and diseases and greater tolerance to water stress in other crops, especially cereals, corn and sorghum.

Potassium sulphate has a low salt index and the added advantage of containing sulphur. It is used in the production of high value fruit and vegetable crops. Potassium sulphate has long been recommended for sensitive crops like tobacco and potatoes where quality is affected by excess chloride.

Potassium fertilizer product development

The global trend to high-concentration fertilizers resulting in significant cost savings in transportation, storage and handling and improved convenience has facilitated acceptance of virtually all potash fertilizers. Common high-concentration potassium products are generally marketed through two main channels, bulk blending and compound or complex fertilizers. Bulk blending is the mechanical mixing of two or more dry granular fertilizer materials to produce mixtures containing variable quantities of N, P, K and other nutrients such as S and magnesium (Mg), as well as micronutrients. It is a proven, practical, and economically attractive method of implementing balanced fertilization. Bulk blending has two very important advantages including flexibility in adjusting nutrient content of the formulation according to specific soil and crop requirements, and the cost of plant nutrients is usually significantly lower than in compound or chemically granulated fertilizers. Compound or chemically granulated fertilizers have the usual favourable physical properties of homogeneous products but they have the disadvantage of providing nutrients in fixed ratios and quantities that are not necessarily appropriate for the intended application. They are also more expensive sources of plant nutrients.

3.2 Potassium fertilization issues

Economics of potassium fertilization

Profitability of potash use depends upon the interrelationships of three factors: the increased yield and quality per unit of K applied, the unit cost of K, and the return realized per unit of crop output. It is generally assumed by agronomists that farmers, especially those in developing countries require the value of the additional output to be at least double the cost of potash (a value/cost ratio > 2) before they will begin using such fertilizers. However, for farmers with low technology, with serious credit and/or capital constraints, or operating under substantial climatic risks, much higher benefit/cost ratios may be necessary for adopting K fertilization.

Ensuring balanced potassium fertilization

Applying plant nutrient in incorrect proportions can trigger a number of unwanted consequences. Unbalanced potassium fertilization has negative effects on crop quality and on crop resistance to pests and diseases. Insufficient potash application results in a significant depletion of soil potash reserves, yield loss and a higher economic risk for farmers. An analysis of the nutrient balances for the period 1961 to 1998 for six Asian countries (China, Indonesia, Malaysia, the Philippines, Thailand and Vietnam) indicated that the overall annual potassium deficit is 250% more than the current potassium fertilizer use.

Excessive use of potash is not linked to any known health or environmental risks, but represents a waste of resources with social and economic consequences. The amount of potassium for sustainable crop production depends upon numerous factors, particularly soil properties, climate, and crop management practices. High levels of added potassium can interfere with magnesium uptake by crops. Leaching losses of soil and fertilizer potassium are a major concern in very sandy soils and in soils of the humid tropics that have low potassium retention properties.

Soil salinity

Potassium fertilizer products with high salinity index increase the salt concentration in the soil solution, which can be detrimental to crop growth, especially at the germination and seedling establishment stages. Potassium chloride and potassium magnesium sulphate have the highest salt indices while potassium sulphate has the lowest among common potassium fertilizers. Salinity affects plant growth either directly by induced water deficit and high levels of cations or indirectly by unbalanced nutrient uptake ratios. Salt tolerance of crops varies depending on the species, on cultivars, but also according to the growth stage of the crop. Measures can be taken to mitigate salinization from fertilization include the choice of potassium source, respecting recommended application rates and adjustments in fertilizer placement to separate the salts from sensitive seeds.

Organic farming

The principles of organic farming require that soil fertility and biological activity should be maintained or increased by the cultivation of legumes, green manures or deep-rooting plants in an appropriate multi-annual rotation programme or by the incorporation in the soil of organic materials. These principles have resulted in determining some restrictions in the use of mineral fertilizers in organic farming. According to the FAO/WHO Codex Alimentarius Commission Guidelines for Production, Processing, Labelling and Marketing of Organically Produced Foods, potassium fertilizers can be used for soil fertilization and conditioning only to the extent that adequate nutrition of the crop or soil conditioning are not possible through the recycling of organic materials alone. Organic farming standards tend to put restrictions on the use mineral potassium (potash containing less than 60% chlorine and potassium sulphate obtained through non-chemical processing). However, these guidelines and standards do not ban the use of potassium fertilizers (SOP, MOP, etc) but restrict their application within a supplementary role to carbon-based materials when addressing long-term fertility needs. This is consistent with the principles of integrated plant nutrition management advocated by the mineral fertilizer industry.

Minor amounts of potassium occur in animal manures and plant residues, composted animal and plant wastes and in various industrial wastes such as flue-dust, and from sugar factory residues; but the potassium content is low and variable. In some areas of the world, removal of crop residues for use as fuel, building material, livestock fodder, or raw material for industrial purposes will further limits the possibility of recycling potassium.

Appendix A

Global Resources and Reserves of Potassium Bearing Deposits

World resources of potassium bearing sedimentary deposits are immense and are reported to total 17 billion tonnes (Bt) (US Geological Survey, 2001). Of this total, 8.4 Bt of K_2O reserves are categorized as commercially exploitable. With current global consumption of about 25.8 Mt K_2O annually, both economical reserves and resource bases are sufficient to meet world demand for centuries.

Canada has the largest known reserves and reserve base of K_2O. Rich. These extensive, consistent and high-grade potash deposits represent more than 50% of estimated world reserves. Most of Canada's reserves are located in thick, flat-lying horizons in the province of Saskatchewan where they extend in a broad belt 720 km long and up to 240 km wide into Manitoba in the east and southward into North Dakota and Manitoba. Rich anticlinal beds occur in New Brunswick.

The sizeable potash deposits in the former Soviet Union contain large amounts of carnallite with associated higher refining costs. Thailand's 10 billion tonnes of potash resources are mostly carnallite, and sylvinite. The vast quantities of K in seawater represent another potential but currently uneconomic supply of this element.

Mining and Beneficiation of Potassium Bearing Deposits

Mining

Potash ores in solid beds at depths no greater than 1400 m below the earth's surface are extracted mainly by conventional mechanized underground mining methods. A variety of mining techniques and equipment are used depending upon such factors as ore body depth, physical properties of the deposit, geological and geotechnical conditions of the ore and surrounding rock, and the occurrence of overlying aquifers. Variations of room and pillar, long-wall, cut and fill, and open stope techniques are commonly used. Ore from the mining face is usually moved by bridge conveyor, shuttle cars or load-haul-dump units to conveyor systems for transfer to underground storage bins to await haulage to the surface in automated skips operating in the mine shafts. Solution mining is employed when underground extraction is no longer feasible because of depth to deposits and/or when water inflow problems interfere with conventional underground mining. This method relies on the greater solubility of sylvite over halite (NaCl) in high temperature brines. Solar evaporation of brines that naturally contain potassium is the third method of obtaining potash ore. Halite and carnallite are precipitated in a succession of ponds, and the carnallite is transferred in slurry form to the beneficiation facilities.

Beneficiation

The steps in the processing of potash ore are usually size reduction-desliming-separation-drying, then compaction or granulation. The following series of steps: crushing and grinding; desliming; separation; drying; and compaction and granulation. The specific processes used depend upon characteristics and composition of the potash ore and market requirements. A system of crushing and grinding is used to separate crystalline minerals and disperse clay slime. Fine materials such as clays and sand are separated from the potash ore in the desliming step, which involves intense agitation followed by either flotation or hydro-cycloning. Four separation processes are used to concentrate the potash: flotation, electrostatic separation, thermal dissolution-crystallization, and heavy media separation. Drying is usually carried out in a rotary or fluid bed dryer. Dried potash is then either granulated or compacted through high-pressure rollers and screened to specific particle sizes.

Potassium containing minerals

Table 1 lists the various potassium containing minerals found in sedimentary deposits and also indicates typical potassium concentrations in these salts. Sylvite, sylvinite, langbeinite, kainite, and carnallite are the minerals of greatest economic importance. Sylvinite, a mixture of potassium and sodium chloride crystals, is the easiest to process and thus it is mined and refined in the greatest quantities to produce potassium chloride (MOP), the predominant potassium fertilizer salt. In some potash deposits, less common minerals are important such as langbeinite and kainite.

Table 1. Potassium minerals present in potash deposits.

MINERAL	COMPOSITION	Percent K_2O
Chlorides :		
Sylvinite	$KCl \cdot NaCl$ mixture	Approx. 28.0
Sylvite	KCl	63.1
Carnallite	$KCl \cdot MgCl_2 \cdot 6H_2O$	17.0
Kainite	$4KCl \cdot 4MgSO_4 \cdot 11H_2O$	18.9
Hanksite	$KCl \cdot 9Na_2SO_4 \cdot 2Na_2CO_3$	3.0
Sulfates :		
Polyhalite	$K_2SO_4 \cdot 2MgSO_4 \cdot 2CaSO_4 \cdot 2H_2O$	15.5
Langbeinite	$K_2SO_4 \cdot 2MgSO_4$	22.6
Leonite	$K_2SO_4 \cdot MgSO_4 \cdot 4H_2O$	25.5
Schoenite	$K_2SO_4 \cdot MgSO_4 \cdot 4H_2O$	23.3
Krugite	$K_2SO_4 \cdot MgSO_4 \cdot 4CaSO_4 \cdot 2H_2O$	10.7
Glaserite	$3K_2SO_4 \cdot Na_2SO_4$	42.6
Syngenite	$K_2SO_4 \cdot CaSO_4 \cdot H_2O$	28.8
Aphthitalite	$(K, Na)_2SO_4$.	⋆ 29.8
Kalinite	$K_2SO_4 \cdot Al2(SO4) \cdot 24H_2O$	9.9
Alunite	$K_2 \cdot Al_6(OH)_{12} \cdot (SO_4)_4$	11.4
Nitrates :		
Niter	KNO_3	46.5

Source: International Fertilizer Development Center and United Nations Industrial Development Organization, Fertilizer Manual. Reference Manual IFDC-R-. Muscle Shoals, AL: IFDC, 1979.
Notes: ⋆ Assuming equimolecular proportions of potassium and sodium.