REUSE AND RECLAMATION OF PHOSPHOGYPSUM

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ABSTRACT

Phosphogypsum (PG) is a gypsum byproduct of the phosphate fertilizer industry and is produced at a rate of five tonnes of PG per tonne of phosphate fertilizer. It is estimated that over 3 billion tonnes of gypsum have been accumulated in stacks worldwide. Although PG is classified as NORM (naturally occurring radioactive material), all evidence suggests that no restrictions on reuse are necessary and PG is being increasingly being reused worldwide in agriculture, construction and for roadbase. Phosphogypsum can also be used beneficially *in situ* to grow high value crops and concentrated tree plantations. Research has shown that mixing small amounts of soil into the gypsum creates a high performance Anthrosol that results in greater vegetation health and biomass over plants grown in soil alone. Concentrated woody plantations of willow and hybrid poplar have been established on 25 hectares of PG stacks at the Nutrien facility in Fort Saskatchewan, Alberta, Canada. These trees are sequestering carbon at a rate of 30 Mg CO2 eq/ha/year to combat climate change while producing woody biomass that can potentially be used for green energy. The woody plantations have been shown to be sustainable and environmentally protective while preventing water infiltration into the stacks.

INTRODUCTION

Phosphogypsum (PG) is produced when phosphate rock is treated with sulphuric acid during the manufacture of phosphoric acid, and is composed mostly of gypsum ($CaSO_4 \cdot 2H_2O$). In North America, the gypsum is traditionally stockpiled in stacks that can cover hundreds of acres and be over 100 feet high. In Canada, it is estimated that there are more than 100 million tonnes of stockpiled phosphogypsum, while there are nearly 2 billion tonnes of stacked PG in the United States. Phosphogypsum is typically acidic due to residual acid being present in the pore fluids. The major impurity is quartz sand carried through the process stream. Residual P and F, as well as trace components in the apatite rock may also be present. Although PG is classified as NORM, the reuse of PG is considered to be safe for most applications because of the low level of the radioactivity.

Nutrien spent some time examining PG reuse opportunities in the 80's and 90's. Among other things, PG was used as a soil amendment for sodic and heavy clay soils, as a calcium and sulfur fertilizer, as an additive in composting manure, and for oil sands tailing remediation. Phosphogypsum was never developed as a product at Nutrien and the focus of the company changed from PG reuse to PG reclamation in the early 2000's. Nutrien still provides PG to local farmers for use in dairy barn bedding or for use as a soil amendment upon request but is not actively developing reuse markets in Canada at this time.

Nutrien has two phosphogypsum stacks in Canada. One is located in Fort Saskatchewan, Alberta where phosphate fertilizer was produced by a predecessor company between 1965 and 1991. Approximately 5 million tonnes of PG were produced during that period. Nutrien's other Canadian PG stack is located near Redwater, Alberta. Phosphate fertilizer was produced in this location for 50 years, resulting in approximately 50 million tonnes of PG covering an area of approximately 275 ha. Phosphate fertilizer production was shut down in April 2019 and there is no longer any phosphogypsum production in Canada.

RECLAMATION AND BENEFICIAL USE OF PG *in situ*

Traditionally, gypsum stacks in North America are regarded as a waste by-product and reclamation involves contouring the piles, covering with soil or a synthetic liner and seeding to a grass mixture. Nutrien began conducting research into alternative methods of reclamation in 2005 in collaboration with the University of Alberta. In the last 15 years, seven students have earned their M.Sc. degrees working on different aspects of this project. Initially research projects examined the depth of soil needed to cover the PG stacks and what grasses to seed, but over time it became apparent that it was beneficial to mix soil into the gypsum to create an Anthrosol rather than using a barrier approach to reclamation. PG/soil mixes were shown to result in greater vegetation health and biomass over plants grown in soil alone. Once soil was mixed into the gypsum and the rooting depth of vegetation was no longer an important consideration, growing trees could be considered , creating the possibility of reducing long term maintenance costs and sequestering carbon dioxide to combat climate change.

Nutrien then partnered with the Canadian Wood Fiber Center, Natural Resources Canada (NRCAN) to test the possibility of establishing concentrated woody plantations on the PG stacks. Nutrien follows the protocols developed by NRCAN to develop high yield afforestation plantations that maximize biomass and carbon accumulation over the short to medium term. Typically, these types of plantations are established on moderate to high quality land across Canada but have proven to be very successful on the PG Anthrosol.

In the prairie provinces of Canada, the primary tree species to be considered for high yield and carbon sequestration afforestation is hybrid poplar (*Populus* spp). Hybrid poplar plantations of 1100 – 1600 stems/ha produce yields of 13.6 – 20 m^3 or 7.3 – 10.8 ODT (oven dried tonnes) ha/yr of above ground woody biomass. The preliminary assessments of below and above ground carbon budgets estimate potential carbon increase of 500-650 t CO_2 eq/ha over a 20-year rotation, or 25 – 32.5 Mg CO_2 eq/ha/y.

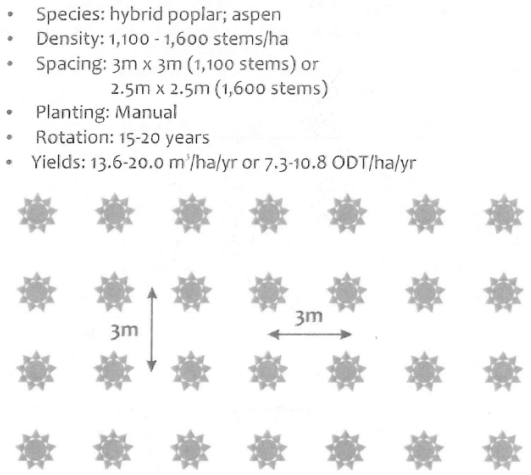

Figure 1. NRCAN Hybrid Poplar Plantation Design

Hybrid willows (*Salix* spp) are also suitable for high yield and bioenergy development. Plantations of 15,625 stems/ha were designed to produce yields of 6 – 12 ODT (oven dried tonnes) ha/yr of above ground woody biomass. Preliminary assessments of below and above

ground carbon budgets estimate potential carbon increases of 14 – 28 Mg CO_2 eq/ha/y over 6-7 three year rotations.

Natural Resources Canada has also designed a mixed wood afforestation plantation using hybrid poplar and white spruce that is designed to maximize biomass accumulation, carbon sequestration and fibre production over both the medium (20 years) and long term (70 years) through the development of both hardwood and softwood crops. Preliminary assessments of below and above ground carbon budgets estimate potential carbon increases of 644-820 Mg CO_2 eq/ha/yr over the 20 and 70 year rotations for the respective hardwood and softwood crops.

Establishing a forest on top of PG stacks has many positive impacts on the environment. The afforestation approach to PG stack reclamation will increase carbon sequestration and generate carbon dioxide offsets as well as produce biomass for energy production. Trees are also capable of phytoremediation of any excess nutrients and water within their rooting zone, thereby improving long term groundwater quality. Field observations indicate that there is little or no water infiltration into the gypsum stack under the concentrated tree plantations in the semi-arid climate of the Canadian prairies. Tree plantations have already been established on 20 ha of phosphogypsum (PG) at the Nutrien facility in Fort Saskatchewan, Alberta, Canada. The trees are growing extremely vigorously. As an example, between 2016 and 2017, the hybrid poplar cultivar *Tristis* grew from an average height of 85 cm to 280 cm, a gain of almost 2 meters height in a single year. Many trees are over 5 meters in height after three years of growth. Crown closure has been observed after less than three years. This inhibits vegetation growth beneath the trees, with the site essentially left in a free-to-grow state without any need for maintenance. Trees are observed to be growing much faster on the gypsum stacks than the same trees growing on regular soil. This is likely because the PG has excellent water holding capacity and some residual plant nutrients.

The tree plantations established at Nutrien are predicted to sequester 30 Mg CO_2 equivalents/ha/year. Thus, in 20 years, the gypsum stack area reclaimed to date will sequester 12,000 metric tonnes of CO_2 equivalents. This same area is also predicted to produce 10 ODT/ha/year of above ground woody biomass; therefore, it is estimated that 4000 green tonnes will be produced in this area over the next 20 years. These numbers will continue to increase as Nutrien continues to reclaim and establish concentrated woody plantations on their PG stacks.

The economic benefits of afforestation can be substantial. Carbon credits are worth $30/tonne in Alberta and therefore it is estimated that the 20 hectares of forested gypsum stack can potentially generate $360,000 in C credits in 20 years. The cost of establishing a short rotation woody crop is approximately $3800/ha, therefore afforestation pays for itself in a few years. If desired, woody biomass could also be sold. Woody biomass is worth approximately $50/tonne in Alberta. It is also important to consider that once the trees close canopy, maintenance is essentially eliminated, so the reduction in maintenance and mowing costs compared to a grassed PG stack can be significant.

Incorporating trees into the reclamation plan will also improve the long-term sustainability and ecosystem diversity of the gypsum stacks. Increased wildlife such as deer, rabbits, foxes, small rodents and many birds have been observed in the forested areas.

Figure 2. Willows planted on a PG filled pond five years after planting.

Figure 3. Hybrid poplars (4 years old) growing on the PG stacks

Figure 4. Some of the 2020 vegetable harvest from the PG Anthrosol research garden.

The phosphogypsum/soil Anthrosol can also be used to grow many other types of high value crops. Nutrien has established a small research garden on top of the PG stack and has tested various flowers, fruits and vegetables such as raspberries, potatoes, tomatoes and pumpkins. Analytical results for trace elements indicate that the quality of the vegetables is the same or better than plants grown on regular soil. Future research will include expanding pollinator habitat and working with local beekeepers to investigate other opportunities to create value *in situ*.