PHOSPHORUS ADSORPTION AND DESORPTION PROPERTIES OF MINNESOTA BASALT LUNAR SIMULANT; B. Sutter1, L.R. Hossner2, D.W. Ming2, and D.L. Henninger2; 1Dept. Soil and Crop, Texas A&M University, College Station, TX 77843, 2NASA-JSC Houston, TX. 77058.

INTRODUCTION. In anticipation of a permanent lunar base, research is being conducted to determine the feasibility of growing crops in lunar soil as a component of NASA’s Advanced Life Support System (ALSS). In order to reduce resupply costs, astronauts will grow crops to produce oxygen, food, and water (plant transpiration) and recycle carbon dioxide. Therefore, it is important to understand how plant nutrients will interact with lunar soil. However, due to the high value and limited amounts of lunar soil available to researchers, lunar simulants are used in plant growth studies. Because phosphorus (P) is an important nutrient for plant growth, it is important to study its interactions with lunar simulants. When P fertilizer is applied to terrestrial soils, P can be adsorbed and rendered unavailable for plant growth [1]. Secondary minerals such as clays, Al and Fe hydrous oxides, calcium carbonate, and poorly crystalline colloids [1] are mostly responsible for P adsorption in terrestrial soils. Adsorbed P can be released (desorbed) to solution in the presence of a sink (e.g., root).

Quantity and intensity parameters have been used to study P adsorption and desorption relationships [2]. Quantity (Q) refers to the amount of P adsorbed in the case of adsorption or desorbed in the case of desorption. Intensity (I) refers to the amount of solution P. By plotting Q versus I, a Q/I curve can be obtained. The first derivative of the Q/I curve is referred to as the buffering capacity (dQ/dI) and is plotted as a function of I. Buffering capacity measures the soil’s ability to maintain I as P is adsorbed or desorbed [2]. When P is added to a soil solid phase with a high adsorption dQ/dI, P will be adsorbed to the solid phase, and I will be maintained at a low value. If the adsorption dQ/dI is low, then added P will not be strongly adsorbed to the solid phase, causing an increase in I. A high desorption dQ/dI soil has an adsorbed reserve of P that maintains I by desorption as a plant absorbs P. A low desorption dQ/dI terrestrial soil does not readily desorb its adsorbed P and I decreases as solution P is removed by the plant. Also, a terrestrial soil could have a limited supply of available P, and once it is all desorbed, no P remains to replace solution P removed by the plant. The objective of this study was to use Q/I relationships to understand MBLS P interactions to establish P requirements for wheat growing in MBLS.

MATERIALS AND METHODS. The lunar simulant used in this study is known as Minnesota Basalt Lunar Simulant (MBLS), and it comes from a one- to two-meter thick by 50 meters long sill which is found along a rock face in a quarry in Duluth, Minnesota [3]. The simulant is ground and sieved to have the same size fractionations as Apollo 11 sample 10084. The MBLS material also has bulk chemical composition similar to 10084.

Characterization of MBLS included mineralogy determination using X-ray diffraction and total P analysis [4]. Phosphorus adsorption Q/I relationships were obtained by adding P treatments ranging from 0-25 mg P/kg to 1 g MBLS samples followed by incubation at 0.03 MPa moisture tension and controlled environmental conditions for seven days. After the incubation, 10 ml of water was added to MBLS and the slurry was shaken for one hour, followed by determination of adsorbed P (Q_a) and solution P (I_s). Two g MBLS samples were incubated at 0.03 MPa moisture tension for seven days with 10 mg P/kg P additions in the desorption studies. After the incubation, 20 ml of water and variable quantities of anion-exchange resin (0-1g) were added to the samples, followed by shaking for 3 days. The anion-exchange resin mimics plant roots by removing P from solution. The amount of P adsorbed by the resin (Q_r) and solution P (I_s) were determined and used to develop Q/I desorption curves. Kinetic desorption curves (Q_d versus time) were obtained using the desorption procedure; however, one gram resin weights were used and samples were removed at time intervals from 0-60 hours. Equations were fitted to the Q/I curve and Q/I curves and buffering capacities determined. Wheat was grown in MBLS for 50 days under controlled conditions. After harvest, total dry wheat weight was measured along with MBLS solution P concentration.

RESULTS AND DISCUSSION. X-ray diffraction data (XRD) indicated that anorthite, augite and ilmenite were the dominant minerals in MBLS. Total P analysis found 140 mg P/kg in MBLS. This is a low value when compared to most terrestrial soils (avg. total P is 382 mg P/kg) [1]. The P adsorption Q/I data showed that as more P was added both adsorbed P and solution P increased (Fig. 1). The adsorption data were best described by the Extended Freundlich equation [5] (Q_a = a_1 b^c + c; r^2 = 0.97) where Q_a is adsorbed P, I_s is solution P, and a, b and c are fitting parameters. The adsorption buffering capacity (dQ_a/dI_a) was determined to be 20 L/kg at 0.1 mg P/L which is low when compared representative Texas soils (37 - 252 L/kg) [6]. A low dQ_a/dI_a indicated that MBLS adsorbed low amounts of applied P, leaving substantial amounts of P in the solution. The P desorption Q/I data showed that as Q_d increased I_s decreased (Fig. 2) and was best described by the Raven/Hossner equation [7] (Q_d = a_d b c + b ln(I_d + 1) + c; r^2 = 0.96) where Q_d is desorbed P, I_d is solution P, and a, b and c are fitting parameters.
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Parameters. The desorption relationship (Fig. 2) indicated that most of the applied P (10 mg P/kg) was recovered by the resin. The desorption buffering capacity (dQ_d/dP_d) at 0.1 mg P/L was found to be 49 L/kg which is low when compared to representative Texas soils (66-234 L/kg) [6]. The low dQ_d/dP_d value indicated that P was readily desorbed to the resin and that P_d could not be maintained. Kinetic desorption data indicated that most of the applied P (10 mg P/kg) was released within 15 hours. Most terrestrial soils have an initial rapid release within 15 hours and continue to release more P over time [8]. These data further supported the hypothesis that MBLS will not retain P tightly, and that adsorbed P will be easily released. Kinetic data was best described at <30 hours by the Extended Elovich equation [8] \[ Q_{DT} = a \ln(t + b) + c; r^2 = 0.94 \] and by the t/Q equation \[ Q_{DT} = t(a + bt); r^2 = 0.98 \] at >30 hours where Q_{DT} is desorbed P, t is time, and a, b and c are fitting parameters. The wheat study showed that P treatments beyond 20 mg P/kg did not give a significant increase in wheat dry weight. A solution P value of 0.24 mg P/L was determined at the 20 mg P/kg treatment level. Values ranging from 0.2-0.3 mg P/L are recommended for sufficient wheat growth [9], therefore, a 20 mg P/kg application appeared to initially supply sufficient P.

CONCLUSIONS. Adsorption data indicated that MBLS did not strongly adsorb P. Because MBLS was determined to be composed of primary minerals, the secondary minerals that are largely responsible for P adsorption in terrestrial soils are lacking. Desorption and kinetic desorption data indicated that P was not tightly adsorbed and was readily released to the resin. It is recommended that initial small amount of P (10-20 mg P/kg) be applied for optimum wheat growth followed by additional small applications as required. One large P application would provide more P than the wheat requires and result in nutrient imbalances in the wheat plant. Data from this study will assist in establishing methods for future lunar soil/P studies and will aid in predicting P interactions with lunar soil.

Fig. 1. Phosphorus adsorption to MBLS as described by the Extended Freundlich equation (solid line).

Fig. 2. Phosphorus desorption from MBLS as described by the Raven/Hossner equation (solid line).