Optimum Fertilization of Phosphorus to Support Plant Growth within the Waste Material-Peat Mixtures at DeBeers Victor Diamond Mine, Ontario

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Abstract

The De Beers Canada Victor Mine is Ontario's first diamond mine and the first mining venture within the Hudson Bay Lowland. The mining operations have disturbed peatlands and also created new upland deposits, which must be reclaimed and revegetated. Two of the main rehabilitation challenges of this area are the subarctic climate and limited soil phosphorus availability. This study focuses on the amount of phosphorus fertilizer amendments needed to raise the bio-available phosphorus concentrations within covers of mixed peat and calcareous silt overburden to emulate conditions in regional reference sites. During the summer of 2013 an experiment was conducted on the South Overburden site at the Victor Mine. We set up an increasing fertilization series with Calphos rock phosphate, extending from 0.1 g to over 1 kg applied to 2 m^2 plots, at half log intervals. The series was set up in four blocks in late May 2013. Soil samples were collected for pH, conductivity and bioavailable elements before fertilization. Soil samples were collected in mid summer to determine gravimetric water content and bulk density. In late August 2013, soil samples were again taken to measure bioavailable elements. Bioavailable phosphorus increased overtime only in one of 36 plots even thought up to 1 kilogram of rock phosphate was laid down within a $2m^2$ plot. This indicates that time may not have been sufficient for the rock phosphate to dissolve. Excess phosphorus amounts in the soil can harm surface water and ground water resources. Mycorrhizae fungi plants helps prevent such occurrences and can become a potential asset to DeBeers.

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Introduction

Human disturbance have increased in the subarctic, arctic and high boreal environments within the last few decades (Houle & Babeux, 1994), many of which are caused by mining projects (Far North Science Advisory Panel, 2010). Vegetation, soil and parent materials are locally disturbed, removed or buried and replaced with mine installations, mine waste deposits, processing facilities and access roads (AMEC, 2004). The rehabilitation of these mining-related disturbances is required during the closure of mine sites. Reclamation of disturbed sites creates sustainable ecosystems with suitable soil mixtures, nutrient availability, allowing re-vegetation.

Subarctic environments provide many rehabilitation challenges. They have long cold winters and short summers, often with strong prevalent winds (Houle & Babeux, 1994). Discontinuous to continuous permafrost is often present, which slows the establishment and growth of plants (Abraham & Keddy, 2005). Freeze-thaw cycles also create a dynamic active layer, disrupting the soil and the loosely established plants (Riley, 2003). For instance, needle ice in the spring and fall can uproot seedlings, preventing their establishment (Abraham & Keddy, 2005). Suitable microclimates are therefore key challenges to establish plants during reclamation in subarctic environments.

Attention to soils is particularly important during mine rehabilitation to ensure proper re-vegetation of disturbed lands. Soils generally act as a central hub supporting the surrounding ecosystem, and this is certainly the case in subarctic environments (Charbonneau, 2007; Quinty & Rochefort, 2003). Many subarctic soils have low nutrient availability (Verhoeven & Arts, 1987; Lavoie *et al,* 2003). Characteristics limiting re-vegetation for these types of environments are short summers, frost heaving, chemical weathering, precipitation, inoculation and low levels of biological activity (Rantala-Sykes, 2012; Lavoie *et al,* 2003). Soil biota are tightly integrated into these soil chemical processes. For instance, mycorrhizae are symbiotic fungi that mobilize phosphorus, improving bioavailability for other plant species (Grant *et al*, 2005). This is even more true in neutral or calcareous soils as it improve phosphate levels for crops in low phosphorus concentrated soils (Grant *et al*, 2005). Anthropomorphic disturbances have the potential to disrupt soil function in subarctic ecosystems and thereby reduce their biodiversity and overall health.

The availability of sufficient nutrients is of important concern when building suitable soils from mine wastes. Key macronutrients for plants include nitrogen, phosphorus, potassium and sulphur. Many subarctic environments are nutrient-poor (Quested *et al*, 2002). Phosphorus in particular is not an abundant element (Garrah, 2013; Corson 2010), and is often limiting (Hopkins & Ellsworth, 2005). Phosphorus is an essential element necessary for plant growth and development for photosynthesis, cell divisions, development of new tissues, energy transformations, and also the activity of hormones in both plants and animals (Brady & Weil, 2010). Phosphorus is also required for ATP molecules, as it is the rudimentary energy form of organisms within DNA (Brady & Weil, 2010). Phosphorus promotes root growth, winter hardiness, and often hastens maturity (Brady & Weil, 2010). The addition of phosphate improves the success rate of both vascular and non-vascular plant establishment (Wind-Mulder & Vitt, 2000; Belnap *et al*, 2003). Most plants with phosphorus deficiency are unable to grow and are usually stunted and/or lack the normal level of mass and proportions.

Phosphorus is often found at low levels in natural environments. Most boreal and subarctic plants require mycorrhizal associations to obtain sufficient phosphorus (Read *et al*. 2004). A mycorrhizae fungus develops a symbiotic relationship with plant roots which enhances phosphorus bioavailabity. Excess phosphorus can disrupt the symbioses of mycorrhizae decreasing their overall productivity and growth (Grant *et al*, 2005). To encourage mycorrhizal associations, phosphorus fertilization within the soil solutions must not be exceeded, hence added concentrations must remain low (Grant *et al*, 2005). Excess phosphorous amounts in the soil can harm surface water and ground water resources, degrading the quality of aquatic ecosystems (Grant *et al*, 2005). As a result, an optimum amount of phosphorus fertilizer (not too little, not too much) needs to be achieved to acquire satisfactory results for both mycorrhizae and other plant species and avoid nutrient enrichment problems in nearby water bodies.

Phosphate minerals are highly insoluble, thus making them unavailable in a wide range of environmental conditions (Faure, 1998). Phosphorus availability is a particular issue in calcareous soils. These soils are made from carbonate-rich parent materials, such as limestone and dolostone (Brady & Weil, 2010; Hopkins & Ellsworth, 2005), and are rich in calcium. The presence of carbonates affects soil productivity by influencing soil pH, water flow and structure. They especially influence phosphorus availability at higher pH. During the reclamation of carbonate rich substrates, it consequently becomes important to consider the potential binding properties of phosphorus to calcium, making phosphorus unavailable for plant uptake (Devine *et al*, 1968).

The decomposition of organic matter in soils can also reduce and limit nutrient availability. Microbes uptake nutrients and consequently compete for nutrients and limit their availability (Qualls & Richardson, 2000). Research conducted by Qualls and Richardson (2000), firmly demonstrates microbial immobilization of phosphorus as the nutrients are being used to increase peat accretion, litter decomposition and net productivity in the southern everglades.

Mining is increasing in the subarctic portions of Ontario, within the Hudson Bay Lowland (Far North Science Advisory Panel, 2010). This region is a vast peatland, underlain by marine carbonate-rich overburden and bedrock. The rehabilitation of mine sites must consider the mixes of carbonate-rich overburdens and peats to form sustainable soils. We do not know the levels of total phosphorus, but our median levels of bioavailable phosphorus were 0.0 mg P/kg soil to 0.2 mg P/kg soil in best rooting horizons at interior and river reference sites at De Beers, Victor Mine, respectively. Bioavailable phosphorus is found at low levels in natural upland ecosystems in this region (Garrah, 2013). However they exceed the levels of phosphorus available in overburden and in peat. Fertilization is therefore required to bring available phosphorus to within a similar range as found in natural upland environments in this region. Insufficient phosphorus will slow re-vegetation, while an excess of phosphorus could discourage mycorrhizae which most native plant species require. Fertilization is therefore required to create a suitable ecosystem similar to those found in natural upland environments in the region. The question remains, how much fertilization is needed to attain these phosphate concentrations?

The objective of this study was to determine a suitable amount of phosphorus fertilization within mixes of carbonate-rich overburden and peat in order to achieve a proper bioavailable soil concentration.

Methods

Study Site

The site for this experiment was located at the De Beers Victor Mine in the Hudson Bay Lowland (52°48’52” N, 83°53’14” W), approximately 90 kilometres west of the community of Attawapiskat. These peatlands support the world’s third largest wetland and the largest in North America occupying approximately 3.5% of Canada (Riley, 2003). The subarctic environment of the Hudson Bay Lowland is dominated by flat limestone plains with marine sediments overtopped by peat deposits. In terms of climate, the area is known to receive precipitation ranging between 700-800 mm and temperatures as cold as -40°C during the winter and +30°C during the summer (De Beers Canada, 2013). The dominant vegetation in the area is small black spruce (*Picea mariana*) and tamarack (*Larix laricina*), ericaceous shrubs and sphagnum moss, but this region is home of 816 native vascular plant species and 98 non-native species (Ministry of Natural Resources, 2013). With flat poorly drained landscapes, intense winters and sporadic discontinuous permafrost, this landscape introduces many challenges.

In 2008, DeBeers Canada began production of Ontario’s first diamond mine called Victor Mine with the Attawapiskat River drainage of the Hudson Bay Lowland. This open pit mine is estimated to have a mine life of 12 years. Over the course of the mine it is projected that 17.4 million tons of overburden (marine clay and silt), 26 million tons of waste rock (limestone and dolostone) and 1.2 million cubic metres of peat will be distributed and made into uplands (AMEC 2004, De Beers Canada, 2013) similar to my study site. An additional 10.3 million tons of course processed kimberlite and 18.4 million tonnes of fine processed kimberlite is expected to be produces and converted into uplands during the course of the mine (De Beers Canada, 2013). These areas all have to be rehabilitated.

The study site was specifically located on the South Overburden Stockpile, just south of the open pit (Figure 1). This is a stockpile of marine silt sediments, and is raised above the surrounding peatland landscape, forming an upland. Over the past year, a mix of peat and silt overburden was placed overtop to create a suitable substrate up to 1 m thick. The thickness of peat and overburden mixes over the pure overburden below is unknown. Upland sites are regionally rare (Garrah, 2013). According to Riley (2003), upland vegetation communities account for only 10% or less of the Hudson Bay Lowland.

Field Preparation and Sampling

The experiment was set up in four blocks placed on the South Overburden Dump (Figure 1). All blocks were chosen at random keeping a minimum distance of 25 metre between block sections and a 30 metres distance from pre-established plots conducted by DeBeers. This distance decreases the probability of cross contaminated soils. Within each block, nine circular plots measuring $2m^2$ were established, for a total of 36 plots in the four blocks (Figure 1). To limit further possibilities of cross contamination, plots were located a minimum of 4 metres away from each other (Figure 2). Plots within each block had similar soil composition in terms of peat and marine silts. Plots were selected on high elevation areas, and depressions were avoided, reducing variation within treatments and plots. Stakes were placed in the centre of each plot and labelled. A rope with a ring was used to determine the plot limit around the central stake. GPS coordinates where taken at each plot (GPSMap 60Cx, Garmin®). The nine fertilization treatments were randomly assigned to the nine plots within each block (Table 1). This was done by labelling the stakes with a treatment number, shuffling the stakes and placing them randomly within each block. This ensured a non-biased experiment.

Prior to fertilization in late June 2013, three soil samples from each plot were sampled and bulked together in one labelled bag to determine initial phosphate, organic matter content and other chemical parameters. An additional three soil samples in each plot were acquired on the same day but kept separate to determine pH and conductivity and their within-plot variability.

The Calphos® rock phosphate fertilizer consists of untreated, soft, phosphatic clay containing 3% available phosphorus pentoxide (P_2O_5), 20% total phosphorus pentoxide (P_2O_5) and 20%

calcium (Ca). The available NPK fertilizer formula consists of 0-3-0, respectively. The dilution series of fertilizer additions was determined, based on a $2m^2$ spreading area, an approximate spreading depth of 5 cm, and a rated phosphorus availability of 3%. With these parameters, the fertilizer series ranged from 3 to 10,000 mg available P/kg soil, at half $\log_{10}$ intervals (Table 1). Required rock phosphate obtained from Victor Mine and first sorted to remove all phosphate particles larger than 1 cm^2 in diameter. The rock phosphate was then weighed and prepared in appropriate labelled treatment bags for each plot. Twenty-five grams of oven-dried peat was added to treatments with low fertilizer levels to increase the effectiveness of spreading.

Plots were fertilized in late June of 2013. All plot areas where raked in advance to create a smooth and even area for the phosphate fertilization. This also permitted any soil irregularities to be removed. A cardboard measuring 2.5 by 1 metre was then placed around the plots to reduce the effects of winds during fertilization. Once these processing phases were complete, the fertilizer was spread gently and evenly throughout the $2m^2$ plots using a “salt shaker” containing numerous $1cm^2$ holes.

Samples were also collected for gravimetric water content and bulk density two to three days after a short rainfall. The two or three day period after rain certified the presence of a moisture gradient and provided an index of soil moisture between the plots. Samples were stored in closed plastic bags until moisture could be determined in the lab.

In late August of 2013, three soil samples in each plot were again collected and bulked together in one labelled bag for initial phosphate, organic matter content and other chemical parameters. In addition one other soil sample form each plot was collected and kept separate to determine the gravimetric water content as well as their bulk density.

Laboratory Analyses

pH and conductivity (Fisher Scientific) were measured according to the DeForest lab of Ohio University protocols, established January 27th, 2009. The pH metre was calibrated to pH 4, 7 and 10 prior to every day of analysis. Each sample bag was measured independently (2 times x 9 plots x 3 bags x 4 blocks = 216 samples). Approximately 10g of substrates was retrieved from each sample bag and placed individually in a 125ml container and 20ml of distilled water was added. The solutions were mixed with a stir stick for a minimum of 5 minutes.

In order to determine the gravimetric water content, fresh mass of each sample was weighed within 6 hours of being collected in the field. The samples were then air dried until they could be placed in a drying oven for 24h at 105^{o}C. Once dried, the samples were reweighed.

Bioavailable elements were determined by the Elliot Lake Field Station Laboratory at Laurentian University. They wash the soil with dilute lithium nitrate, and determine the elements using ICP-AES (Abedin, 2012). Lithium nitrate was used for this study because it gives a truer estimate of available nutrients for plant uptake under natural pH conditions (Abedin, 2012).

Statistical Analyses

The pH, conductivity, bulk density and gravimetric water content parameters were analyzed using ANOVA with block as a random factor and phosphorus addition as a fixed factor. These univariate analyzes were conducted using STATISTICA® (version 10). Bioavailable chemistry was analyzed using the multivariate stats program Primer-E® (version 6). The Euclidean distance was calculated among samples. The PERMANOVA routine, which is a permutation-based multivariate ANOVA, was used to evaluate the differences in chemistry, with block as a random factor, phosphorus addition as a fixed factor and early versus late summer as a repeated measure. SIMPER analyses were conducted on bioavailable elements to determine which variables were responsible for any differences. Principal component analyses were completed to see if dispersion (cloud) were significantly different before versus after phosphate fertilization.

Table 1: Dosage levels of phosphorus were chosen at half log intervals to see a slow increasing trend. Rock phosphate fertilizer was added to the peat and overburden mixes at De Beers Victor mine using theses concentrations. The highest level 4.5 in grey was expected to excessive available phosphorus.

Treatment level (log available Phosphorus mg/kg)	Plot area (m^2)	Fertilization depth (m)	Volume of treated soil (m^3)	**Rock Phosphate per plot of treated soil (g)**	Dosage of total Phosphate at time 0 (mg P /kg soil)	Dosage of available Phosphate at time 0 (mg available P /kg soil)
0.5	2	0.05	0.1	**0.105**	21	3
1.0	2	0.05	0.1	**0.333**	67	10
1.5	2	0.05	0.1	**1.054**	211	31.6
2.0	2	0.05	0.1	**3.333**	667	100
2.5	2	0.05	0.1	**10.54**	2108	316
3.0	2	0.05	0.1	**33.33**	6666	1000
3.5	2	0.05	0.1	**105.4**	21080	3162
4.0	2	0.05	0.1	**333.33**	66666	10000
4.5	2	0.05	0.1	**1054.1**	210820	31623

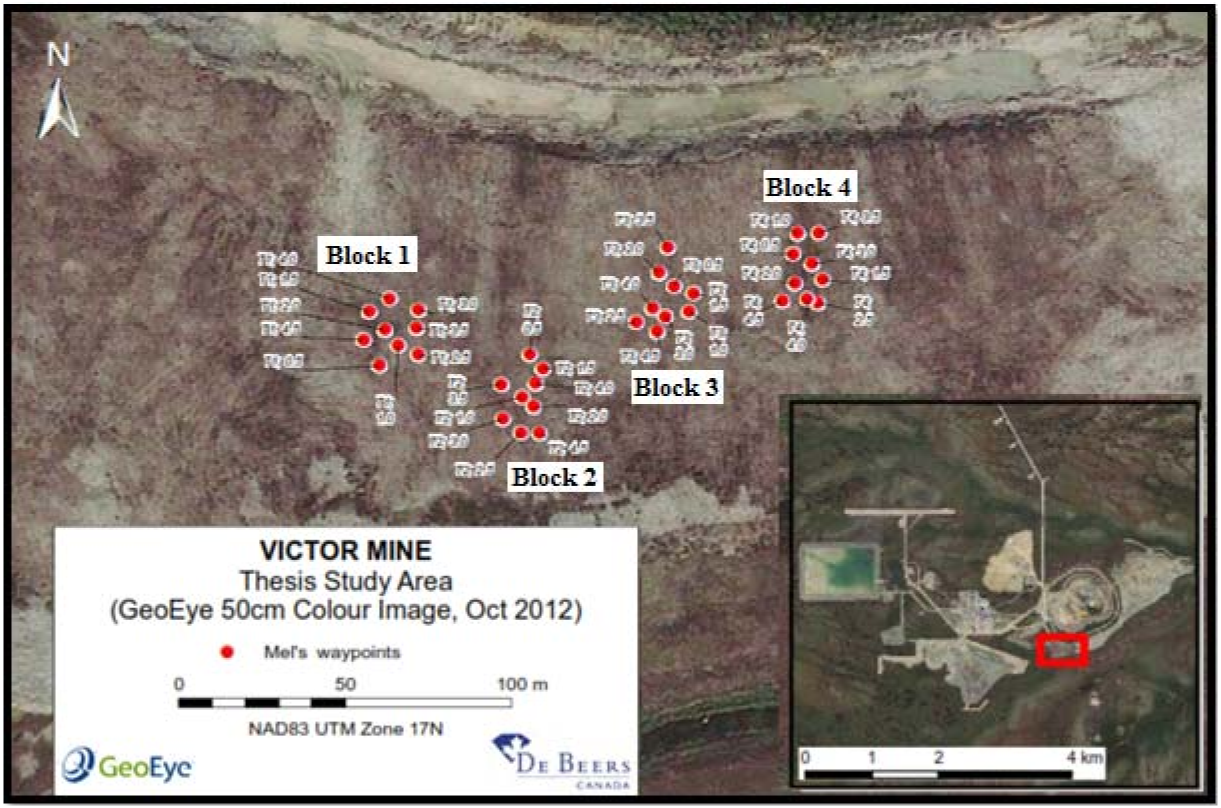

Figure 1: Map of the study site displaying plot positions within blocks on the South Overburden site at De Beers Victor Mine.

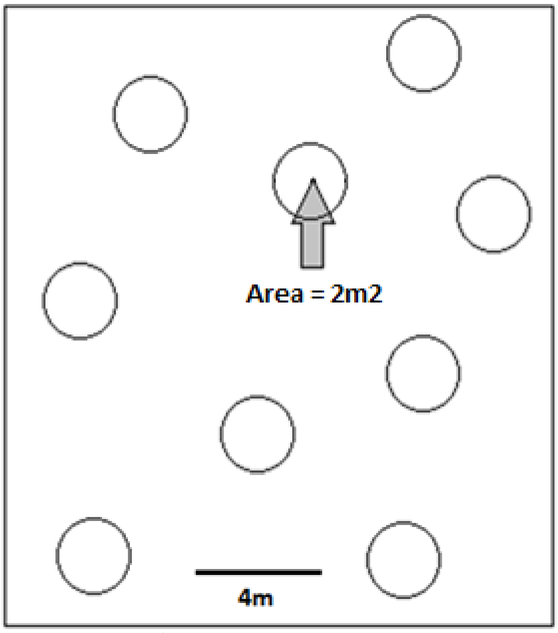

Figure 2: Block representation indicating $2m^2$ plots as well as the minimum distance of 4 metres between each plot. This helps limit the possibilities of cross contamination between plots.

Results

Rock phosphate addition did not affect pH, conductivity, gravimetric water content or bulk density (Table 2). However, pH and conductivity did differ among blocks (Table 2, Figure 3). All blocks were slightly alkaline, with block 4 having the lowest pH (mean pH 7.6) and block 3 having the highest pH (mean pH 7.8; Figure 3a). Mean conductivity also varied strongly along an apparent west to east gradient. Block 1 had a high mean conductivity (>1200 µS cm^{-1}), and this dropped to block 4 to the east (~750 µS cm^{-1}; Figure 3b). Moisture content as determined by gravimetric water content three days after a rain and bulk density did not display any difference among blocks (Figure 3cd).

Bioavailable phosphorus in the surface soil did not increase above the minimum detection limit of 0.1 mg/kg except in one plot (Figure 4), despite the fact that I laid down rock phosphate fertilizers across four orders of magnitude. The only plot to have bioavailable phosphorus above the detection limit was in block 4 at the highest application rate of 1054 g (1kg) of rock phosphate fertilizer within the 2m^2 plot.

Overall, other bioavailable elements did not change as a function of the fertilization with rock phosphate fertilizer, however they did change among blocks and also between the start and the end of the experiment (Table 3). The SIMPER analyses showed that this change among blocks and time were caused by bioavailability of calcium (Ca), magnesium (Mg) and sodium (Na) (salts) elements. Blocks varied once again along an apparent west to east gradient (Figure 5), in a similar manner as the gradient in electrical conductivity. Block 1 and 2 had noticeably higher levels of calcium, magnesium and sodium as compared to blocks 3 and 4**.**

The bioavailability of these elements also varied before and after fertilization (Table 3). Soil samples before fertilization had higher bioavailable concentrations of calcium, magnesium and sodium than after fertilization (Figure 6). The multivariate dispersion did not differ between sampling times (Pseudo-$F_{1,70}$ = 0.92, P = 0.405)

Table 2: Analysis of variance of the effects of blocks and fertilization on pH, conductivity, log gravimetric water content (logGWC) and bulk density. Analyses which are significant are bolded (*P* < 0.05)

		pH			Conductivity			logGWC			Bulk density		
Source	df	MS	*F*	*P*	MS	*F*	*P*	MS	*F*	*P*	MS	*F*	*P*
block	3	0.0487	3.22	**0.041**	389420	5.44	**0.005**	0.0213	1.23	0.321	3.23E-06	1.38	0.274
rock P	8	0.0179	1.18	0.349	55389	0.77	0.629	0.0101	0.58	0.783	1.37E-06	0.58	0.781
error	24	0.0151			71604			0.0173			2.35E-06		

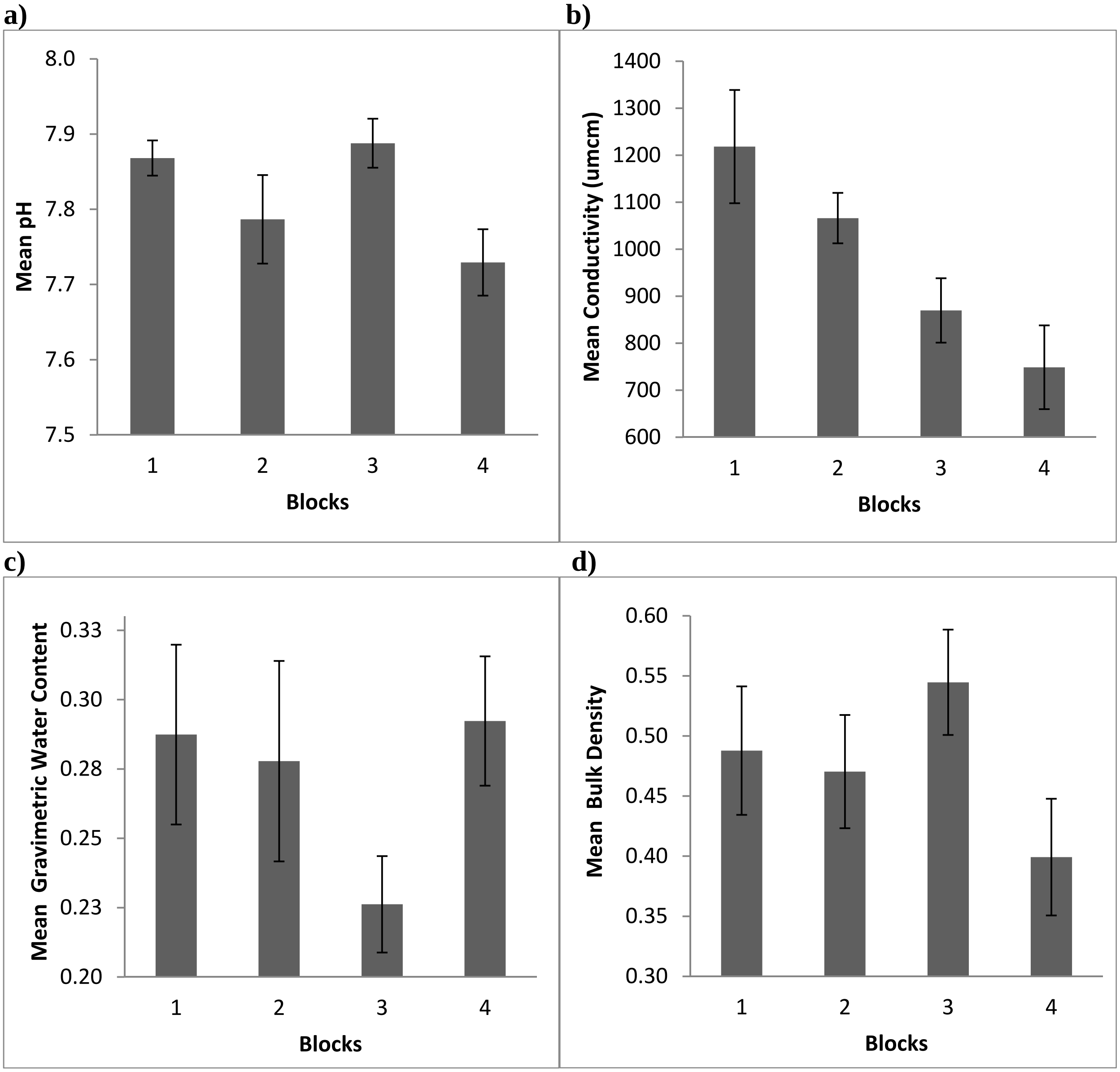

Figure 3: Bar graphs of the variation of pH, conductivity, gravimetric water content and bulk density among blocks (mean ± SE).

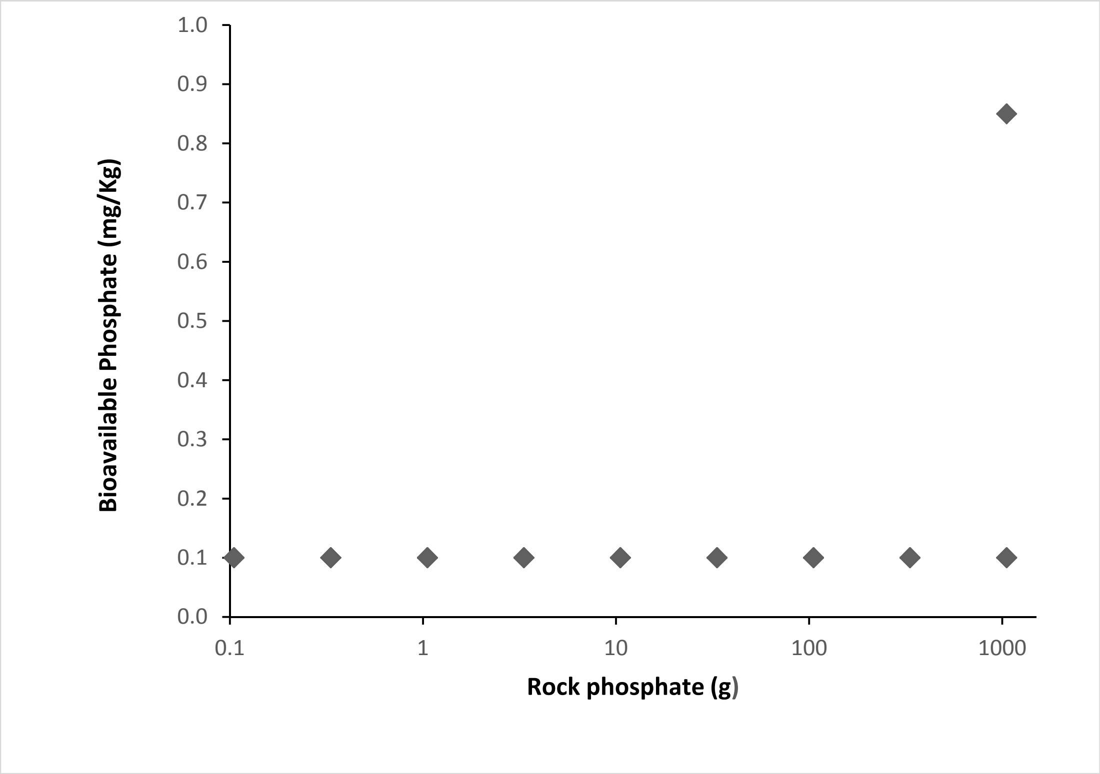

Figure 4: Bioavailable phosphate (mg/kg) within all 9 increasing rock phosphate treatment levels for all 4 blocks. Note that not all 36 plots are visible due to overlap. All plots showed levels below the detectable limit of 0.1mg/kg except for one. Block 4-treatment 9 was the only plot to demonstrate bioavailable phosphate above the detectable limits.

Table 3 : **Multivariate repeated measures analysis of variance of bioavailable elements using the PERMANOVA program.**

Source	df	SS	MS	Pseudo-*F*	*P*
block	3	71.4	23.8	2.30	**0.009**
P	8	75.9	9.5	0.92	0.610
error a	24	248.5	10.4		
time	1	41.0	41.0	3.33	**0.005**
time x P	8	112.6	14.1	1.14	0.218
error b	27	332.9	12.3		

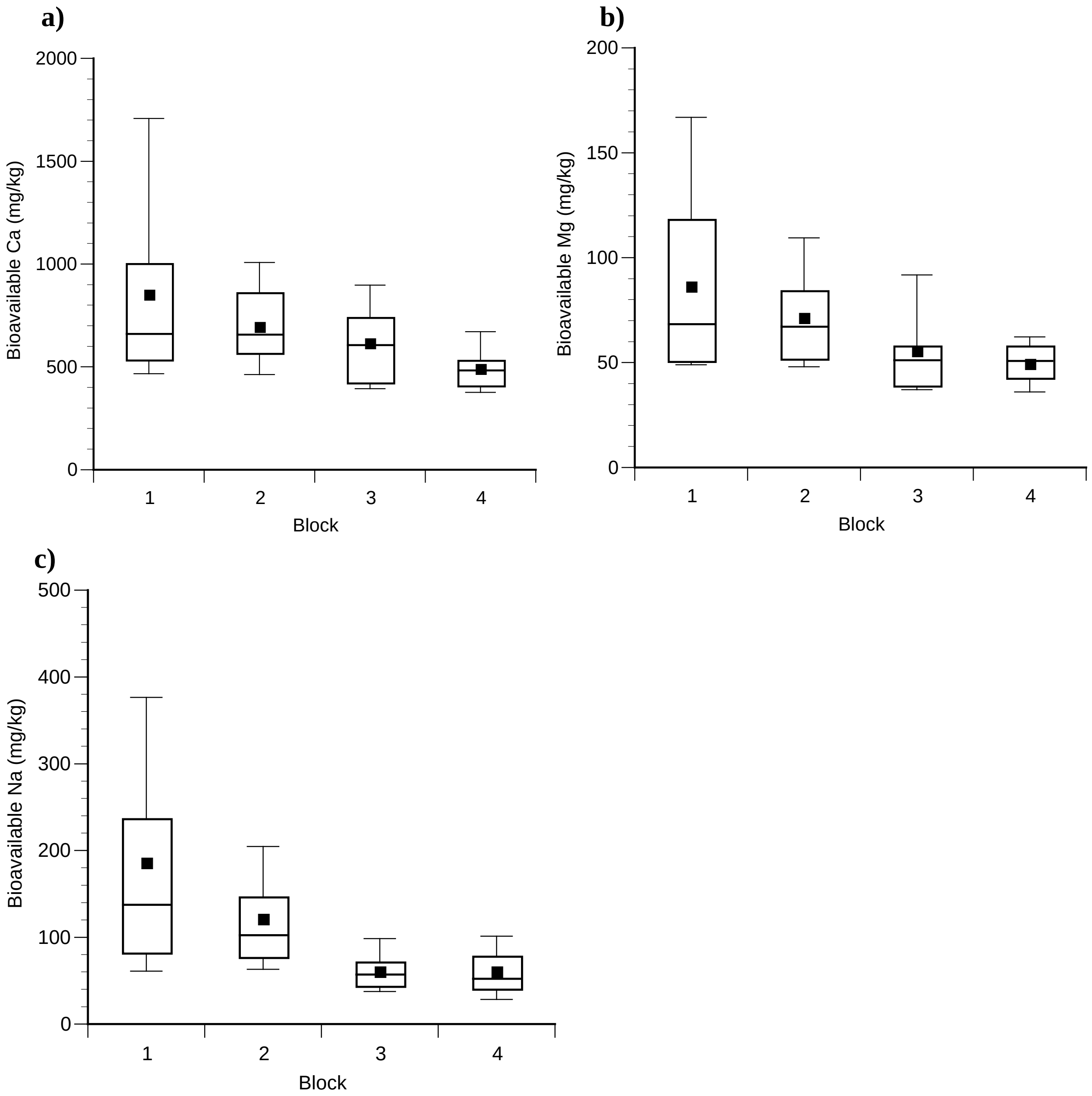

Figure 5: **Box plots of the bioavailable variation of calcium (Ca), magnesium (Mg) and sodium (Na) among blocks (mean ± SE).**

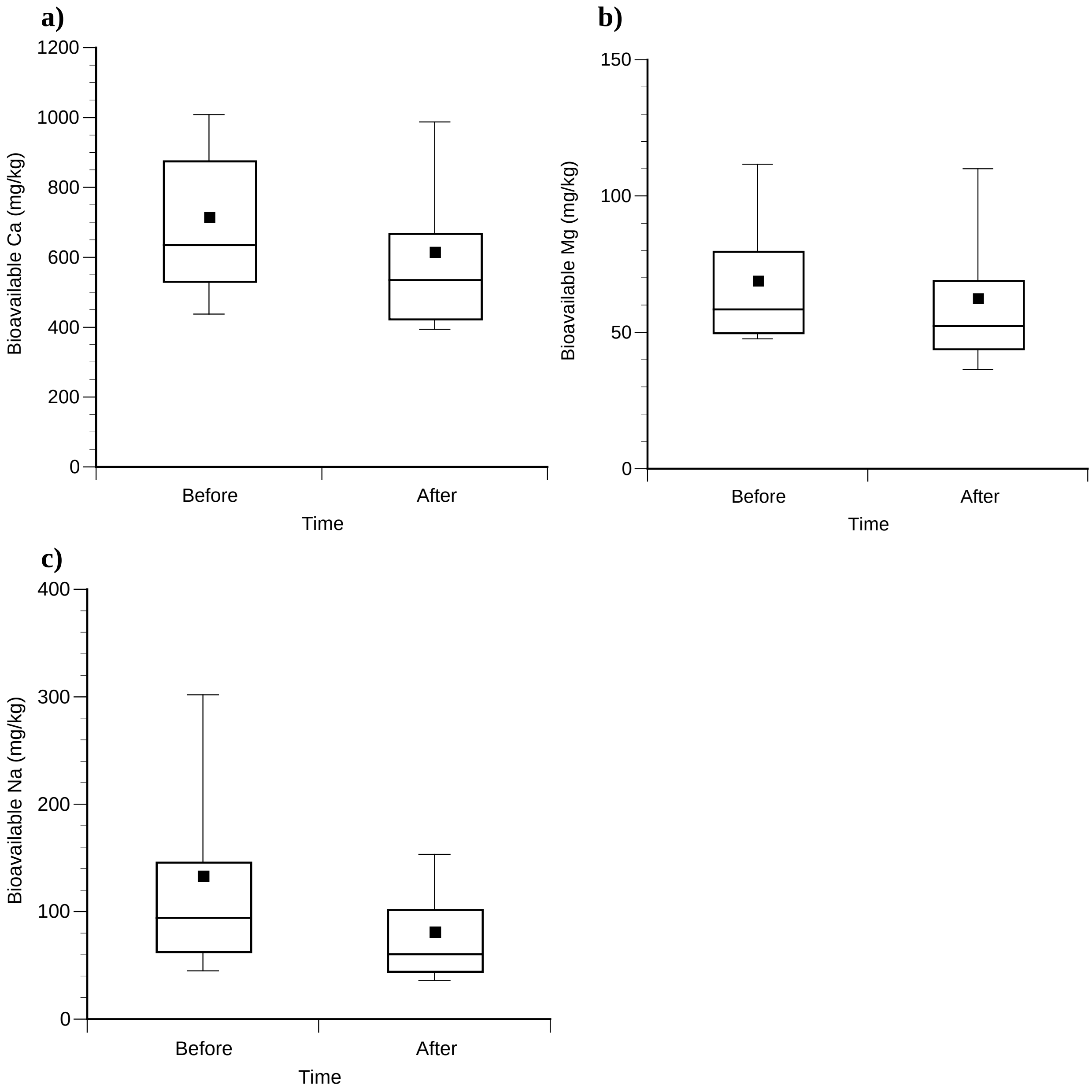

Figure 6: Box plots of the bioavailable elements calcium (Ca), magnesium (Mg) and sodium (Na) before and after fertilization (mean ± SE).

Discussion

The goal of this research project was to establish a suitable level of phosphorus for plant growth and reclamation practices. That leaves us with the question: what proportion of rock phosphate is needed to become bioavailable for plant growth in a peat and overburden soil type at De Beers, Victor Mine. This study showed no rise in phosphorus bioavailability after two months, even though 1 kg of rock phosphate was placed within 2m^2 plots, except in one plot. What were the main influences to disrupt the availability of phosphorus with exception of 1 sample-block 4; treatment 4.5? The hypotheses I consider are (i) dissolution problems due to insufficient time, (ii) phosphorus unavailability due to calcium or peat uptake, as well as (iii) wind influence.

Phosphorus minerals are highly insoluble, restricting its availability in the soil (Faure, 1998). This makes phosphorus one of the main limiting nutrients. Phosphorus is an essential macronutrient, being required by plants in relatively large quantities such as 0.2 to 0.8% (Hopkings & Ellsworth, 2005). Calphos granular rock phosphorus degrades slowly, having a long lasting effect. Rock phosphate which consists mainly of apatite minerals have a slow release unless it is grounded very fine to increase weathering surface and applied to relatively acid soil (Brady & Weils, 2010). The amount of time it takes for phosphorus fertilizer to degrade is still unknown and can be influenced by climate, such as temperature and precipitation. The phosphorus plots at DeBeers, Victor mine were left untouched for a period of 2 months during the summer months. This time frame may not have been sufficient to allow satisfactory amounts of dissolve phosphorus to enter the soil. This hypothesis can be supported by a study conducted by Andrea Hanson at DeBeers Victor Mine in 2014. Her study has shown phosphorus levels ranging between 0.2 and 1.6 mg/L in her respected sites (Hanson, 2014). The differences between her study and mine is that Calphos rock phosphate was applied at a rate of approximately 4.25g/m^2, but were left stagnant for approximately 11 months before she sampled (Hanson, 2014). With an additional 9 month waiting period, her plots displayed a difference of up to 1.5mg/L in available phosphorus. Many other studies also indicate similar trends demonstrating that the rate of granular phosphate as used at Victor mine is a slow process (Devine et al, 1968; Quinty & Rochefort, 2003).

Bioavailable phosphorus is strongly affected by soil pH. The soil pH for optimum phosphorus availability is approximately 6.5 (Hopkins & Ellsworth, 2005). The reduced phosphorus availability in high pH (alkaline) is driven by the reaction of phosphorus and calcium (Hopkins & Ellsworth, 2005). The solubility outcome of calcium phosphate minerals is lowest around pH 8 (Devine *et al*, 1968). This indicates that phosphate can react with calcium to form Apatite, making calcium and phosphorus both insoluble. This can also explain the drop is available calcium after phosphorus fertilization. This hypothesis is supported by Devine *et al* (1968) and Hopkins & Ellsworth (2005) who show that lower rates of phosphorus and calcium dissolution can be found within calcareous soils.

The decomposition of organic matter in soils can also reduce and limit nutrient availability. Microbes uptake nutrients and consequently compete and limit their availability (Qualls & Richardson, 2000). Research conducted by Qualls and Richardson (2000), firmly demonstrates microbial immobilization of phosphorus as the nutrients are being used to increase peat accretion, litter decomposition and net productivity in the southern everglades.

High prevent winds also dominated the landscape that could have influenced how much phosphorus remained in the 2m2 plot sections. Although this is a possibility I feel as though wind was not a main contributor to the lack of bioavailable phosphorus. When I sampled in late August, rock phosphorus was still very noticeable within the plots.

What can further be done to meet the initial objective? In my opinion, allowing a longer waiting period before sampling phosphorus will strongly enhance the results, as seen in Andrea Hanson's study. As mentioned rock phosphorus was initially made to disintegrate slowly to create a long lasting effect, thus, this waiting period can make all the difference. Another suggestion is adjusting the quantity of added phosphorus. Adding additional phosphorus could also be a potential solution, yet this is unlikely due to the fact that 1kg/m^2 should already be an excessive amount. Restoration is a learning experiment and needs to be done properly to create a suitable environment for the ecosystem.

Given the nature of this research study, bioavailable phosphorus concentration will help with the growth of vegetation, but we must consider the threats of over-fertilizing phosphorus. Such potential applications can surely harm the environment in more ways than one (Grant *et al*, 2005). Excess phosphorus amounts in the soil can harm surface water and ground water resources, degrading the quality of aquatic ecosystems (Grant *et al*, 2005). Mycorrhizae fungi plants can help prevent such occurrences and can be a potential asset to DeBeers. A mycorrhizae fungus develops a symbiotic relationship with plant roots which enhances phosphorus bioavailabity. Excess phosphorus can disrupt the symbioses of mycorrhizae decreasing their overall productivity and growth (Grant *et al*, 2005; Read *et al*. 2004). To encourage mycorrhizal associations, phosphorus fertilization within the soil solutions must not be exceeded (Grant *et al*, 2005). As a result, an optimum amount of phosphorus fertilizer needs to be achieved to acquire satisfactory results for both mycorrhizae and other plant species. This assures that over fertilization will not be done. It has been said that less soluble forms of phosphorus, such as rock phosphate has less effect on phosphorus supply to plants, hence mycorrhizae associations may be especially important when less soluble phosphorus forms are used for crop production (Grant et al, 2005).

Phosphorus is important to consider during restoration at Victor mine. Other potential sources such as bone meal (6-12-0) or bio solids can be used to increase phosphorus levels. Bone meal for instance also increases nitrogen levels. It is important to consider wither this would be beneficial for restoration at the Victor Diamond Mine. Biosolids obtained from the Victor camp can also be an alternative. This strategy can be cost efficient and help minimize the amount of non-reclaimed waste water. Again it is important to consider the additional potential nutrients released by this process. It is interesting to consider all the potential assets to overcome the low bioavailable phosphorus levels.

Conclusion

To conclude, after a period of two months, rock phosphorus fertilizer did not increase the phosphorus bioavailability within the peat and overburden soil type mixtures at DeBeers Victor mine. Future research would be beneficial in order to test the plots once again in 2014-2015. This will not only help determine a suitable amount of available phosphorus, it will also help estimated the rate of rock phosphate release in a natural subarctic environment. These plots can also be used for years to come to see the stability of the rock phosphate fertilization.

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Appendices

Appendix A: Raw data for various parameters.

Block	Rock phosphate (g)	pH	Conductivity (um/cm)	Gravimetric Water Content	Bulk density
1	0.105	7.87	1774.00	0.19	0.642
2	0.105	7.84	776.00	0.27	0.439
3	0.105	7.82	806.33	0.22	0.568
4	0.105	7.46	987.33	0.37	0.273
1	0.333	7.80	1033.00	0.21	0.623
2	0.333	7.72	1211.33	0.21	0.637
3	0.333	7.99	791.67	0.17	0.749
4	0.333	7.73	495.67	0.31	0.231
1	1.054	7.83	1043.67	0.49	0.235
2	1.054	7.81	975.33	0.22	0.564
3	1.054	7.75	1279.67	0.29	0.386
4	1.054	7.78	974.33	0.21	0.555
1	3.333	7.85	1016.00	0.37	0.296
2	3.333	7.93	1155.33	0.18	0.588
3	3.333	8.00	688.00	0.22	0.533
4	3.333	7.84	568.67	0.36	0.212
1	10.54	7.99	898.67	0.24	0.575
2	10.54	7.34	1251.33	0.52	0.196
3	10.54	7.91	880.00	0.18	0.732
4	10.54	7.65	951.67	0.30	0.419
1	33.33	7.83	1299.33	0.33	0.334
2	33.33	7.88	964.67	0.38	0.321
3	33.33	7.93	573.67	0.31	0.427
4	33.33	7.76	1095.33	0.23	0.494
1	105.4	7.93	1271.00	0.30	0.462
2	105.4	7.89	1246.00	0.23	0.535
3	105.4	7.92	952.00	0.25	0.457
4	105.4	7.69	805.33	0.30	0.427
1	333.33	7.94	815.67	0.22	0.594
2	333.33	7.81	974.00	0.27	0.419
3	333.33	7.94	817.00	0.16	0.606
4	333.33	7.94	430.00	0.37	0.351
1	1054.1	7.78	1815.67	0.25	0.630
2	1054.1	7.86	1041.67	0.20	0.534
3	1054.1	7.74	1041.33	0.24	0.443
4	1054.1	7.71	431.33	0.19	0.631

Appendix B: Nutrient availability before and after phosphorus fertilizer addition.

				Al	As	B	Ba	Ca	Cd	Co	Cr	Cu	Fe	K	Mg	Mn	Mo	Na	Ni
				mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg
Block	**PO4 treatment**	**Time**	**Detection limits**	**1**	**0.1**	**1**	**0.1**	**1**	**0.01**	**0.05**	**0.1**	**0.1**	**0.5**	**0.5**	**0.5**	**0.1**	**0.1**	**0.5**	**0.2**
B1	0.5	B		10.6	0.174	1.69	0.292	1010	0.01	0.05	0.1	0.1	0.5	103	130	0.1	0.1	375	0.2
B1	1.0	B		29.5	0.1	1.49	0.293	508	0.01	0.05	0.1	0.1	19.6	43	48.5	0.189	0.1	138	0.2
B1	1.5	B		10.5	0.247	1	0.266	890	0.01	0.05	0.1	0.1	0.87	69.1	86.8	0.1	0.1	236	0.2
B1	2.0	B		10.4	0.185	1	0.268	992	0.01	0.05	0.1	0.1	0.895	48	86.8	0.1	0.1	309	0.2
B1	2.5	B		7.1	0.236	1	0.182	592	0.01	0.05	0.1	0.1	2.77	48.7	59.6	0.136	0.1	137	0.2
B1	3.0	B		7.2	0.141	1	0.139	678	0.01	0.05	0.1	0.1	2.97	13	54.9	0.1	0.1	85	0.2
B1	3.5	B		8.26	0.281	1	0.227	1420	0.01	0.05	0.1	0.1	0.5	28.2	141	0.1	0.1	167	0.2
B1	4.0	B		13.4	0.109	1	0.197	540	0.01	0.05	0.1	0.1	15.3	33	58.3	0.149	0.1	64.3	0.2
B1	4.5	B		8.42	0.274	1	0.276	1830	0.01	0.05	0.1	0.1	0.5	80.7	178	0.1	0.1	634	0.2
B2	0.5	B		19	0.1	1	0.211	437	0.01	0.05	0.1	0.1	21.1	30.1	50.2	0.225	0.1	83.4	0.2
B2	1.0	B		8.48	0.185	1	0.205	956	0.01	0.05	0.1	0.1	4.98	49.6	113	0.1	0.1	162	0.2
B2	1.5	B		6.49	0.457	1	0.136	629	0.01	0.05	0.1	0.1	1.88	22.3	52.3	0.1	0.18	88.2	0.2
B2	2.0	B		8.31	0.1	1	0.157	611	0.01	0.05	0.1	0.1	5.18	39.6	61.5	0.1	0.1	123	0.2
B2	2.5	B		13.4	0.401	1	0.203	683	0.01	0.05	0.1	0.1	14.3	60.9	84	0.15	0.1	223	0.2
B2	3.0	B		7.97	0.1	1	0.182	1030	0.01	0.05	0.1	0.1	1.29	84.9	96.9	0.1	0.1	370	0.2
B2	3.5	B		6.54	0.2	1	0.167	859	0.01	0.05	0.1	0.1	0.777	30.1	68.3	0.1	0.1	104	0.2
B2	4.0	B		5.16	0.128	1	0.159	573	0.01	0.05	0.1	0.1	1.09	32.5	54.8	0.1	0.1	78.4	0.2
B2	4.5	B		7.26	0.177	1	0.155	918	0.01	0.05	0.1	0.1	0.739	32.5	75.1	0.1	0.1	115	0.2
B3	0.5	B		6.87	0.256	1	0.137	636	0.01	0.05	0.1	0.1	2.92	32.8	57.6	0.1	0.1	71.1	0.2
B3	1.0	B		7.77	0.461	1	0.129	443	0.01	0.05	0.1	0.1	8.43	25	36.4	0.141	0.1	58.6	0.2
B3	1.5	B		6.53	0.449	1	0.146	840	0.01	0.05	0.1	0.1	0.638	31.5	74.8	0.1	0.1	99.2	0.2
B3	2.0	B		6.16	0.492	1	0.129	630	0.01	0.05	0.1	0.1	0.961	18.4	51.6	0.1	0.1	60.6	0.2
B3	2.5	B		6.64	0.1	1	0.133	582	0.01	0.05	0.1	0.1	2.91	28	50.7	0.1	0.1	129	0.2
B3	3.0	B		6.94	0.1	1	0.138	546	0.01	0.05	0.1	0.1	4.61	29.3	48.7	0.1	0.1	64.5	0.2
B3	3.5	B		6.6	0.1	1	0.183	738	0.01	0.05	0.1	0.1	2.95	23.2	57.3	0.1	0.1	90.3	0.2
B3	4.0	B		5.88	0.223	1	0.136	678	0.01	0.05	0.1	0.1	1.3	23.4	47.5	0.1	0.1	96.8	0.2
B3	4.5	B		6.72	0.1	1	0.201	921	0.01	0.05	0.1	0.1	0.5	39.8	99	0.1	0.1	57	0.2
B4	0.5	B		6.27	0.1	1	0.148	634	0.01	0.05	0.1	0.1	1.29	32.4	62	0.1	0.1	153	0.2
B4	1.0	B		6.12	0.24	1	0.135	415	0.01	0.05	0.1	0.1	5.3	16.9	40	0.1	0.1	41.9	0.2
B4	1.5	B		5.64	0.298	1	0.151	687	0.01	0.05	0.1	0.1	0.982	26.7	62.5	0.1	0.1	93.6	0.2
B4	2.0	B		6.2	0.1	1	0.122	448	0.01	0.05	0.1	0.1	4.67	12	36.7	0.1	0.1	58	0.2
B4	2.5	B		6.56	0.1	1	0.142	530	0.01	0.05	0.1	0.1	4.31	39.6	49	0.1	0.1	43.2	0.2
B4	3.0	B		6.48	0.1	1	0.135	729	0.01	0.05	0.1	0.1	0.919	19	62.4	0.1	0.1	94.8	0.2

B4	3.5	B	5.88	0.48	1	0.124	523	0.01	0.05	0.1	0.1	3.75	20.9	48.2	0.1	0.1	68.4	0.2
B4	4.0	B	10.2	0.172	1	0.16	412	0.01	0.05	0.1	0.1	11.5	33.5	58.5	0.123	0.1	43.6	0.2
B4	4.5	B	13.2	0.251	1	0.16	351	0.01	0.05	0.1	0.1	16.3	24	56.8	0.164	0.1	27.7	0.2
B1	0.5	A	5.92	0.1	1	0.188	643	0.01	0.05	0.1	0.1	0.5	41.3	76.9	0.1	0.1	132	0.2
B1	1.0	A	5.51	0.26	1	0.123	465	0.01	0.05	0.1	0.1	2.28	16.2	42.7	0.1	0.1	59.6	0.2
B1	1.5	A	6.61	0.1	1	0.188	876	0.01	0.05	0.1	0.1	0.5	32.5	81.1	0.1	0.1	170	0.2
B1	2.0	A	4.88	0.1	1	0.14	557	0.01	0.05	0.1	0.1	0.903	31.5	51.3	0.1	0.1	83.8	0.2
B1	2.5	A	7.43	0.351	1	0.139	419	0.01	0.05	0.1	0.1	6.99	21.8	50.4	0.1	0.117	68.6	0.2
B1	3.0	A	6.08	0.1	1	0.127	607	0.01	0.05	0.1	0.1	1.24	14.2	52	0.1	0.1	102	0.2
B1	3.5	A	7.3	0.146	1	0.288	1930	0.01	0.05	0.1	0.1	0.5	42.5	199	0.1	0.1	179	0.2
B1	4.0	A	6.73	0.317	1	0.134	469	0.01	0.05	0.1	0.1	5.34	20.8	49.8	0.1	0.1	56.3	0.2
B1	4.5	A	6.78	0.1	1	0.214	1000	0.01	0.05	0.1	0.1	0.5	59.7	118	0.1	0.139	377	0.2
B2	0.5	A	10.3	0.1	1	0.133	395	0.01	0.05	0.1	0.1	13.5	23.3	35.6	0.149	0.1	60.9	0.2
B2	1.0	A	7.23	0.1	1	0.224	1110	0.01	0.05	0.1	0.1	0.5	45.4	133	0.1	0.1	80.5	0.2
B2	1.5	A	5.57	0.1	1	0.144	700	0.01	0.05	0.1	0.1	1.18	26.9	71.7	0.1	0.1	68.5	0.2
B2	2.0	A	5.36	0.1	1	0.149	525	0.01	0.05	0.1	0.1	0.583	33.6	52.2	0.1	0.1	59.7	0.2
B2	2.5	A	8.49	0.108	1	0.139	583	0.01	0.05	0.1	0.1	6.98	31.7	47	0.101	0.1	146	0.2
B2	3.0	A	6.31	0.335	1	0.154	616	0.01	0.05	0.1	0.1	2.65	40.2	66	0.1	0.1	154	0.2
B2	3.5	A	6.19	0.187	1	0.159	691	0.01	0.05	0.1	0.1	0.796	36.4	101	0.1	0.1	112	0.2
B2	4.0	A	6.42	0.1	1	0.16	764	0.01	0.05	0.1	0.1	0.955	37.7	75	0.1	0.1	76.8	0.2
B2	4.5	A	5.12	0.1	1	0.123	544	0.01	0.05	0.1	0.1	1.36	27.3	54.3	0.1	0.1	101	0.2
B3	0.5	A	5.49	0.1	1	0.115	386	0.01	0.05	0.1	0.1	4.23	21.9	38.6	0.115	0.1	20.9	0.2
B3	1.0	A	3.55	0.1	1	0.116	427	0.01	0.05	0.1	0.1	4.59	20.8	39.5	0.1	0.127	41.8	0.2
B3	1.5	A	6.58	0.193	1	0.128	429	0.01	0.05	0.1	0.1	5.79	20.9	46.5	0.1	0.1	42.3	0.2
B3	2.0	A	5.47	0.147	1	0.121	378	0.01	0.05	0.1	0.1	6.2	16.8	36.1	0.101	0.1	35.4	0.2
B3	2.5	A	6.52	0.214	1	0.134	411	0.01	0.05	0.1	0.1	8.11	21.5	39.2	0.107	0.1	46.6	0.2
B3	3.0	A	6.36	0.388	1	0.14	565	0.01	0.05	0.1	0.1	4.63	32	53.7	0.1	0.119	50.5	0.2
B3	3.5	A	6.69	0.1	1	0.138	642	0.01	0.05	0.1	0.1	2.39	21.6	56.2	0.1	0.1	56.9	0.2
B3	4.0	A	6.17	0.326	1	0.152	814	0.01	0.05	0.1	0.1	0.736	22.4	63.9	0.1	0.1	45.3	0.2
B3	4.5	A	6.58	0.112	1	0.194	1130	0.01	0.05	0.1	0.1	0.5	37.9	111	0.1	0.1	50.5	0.2
B4	0.5	A	6.73	0.1	1	0.141	571	0.016	0.05	0.1	0.1	5.46	25.5	57.6	0.1	0.1	104	0.2
B4	1.0	A	6.17	0.1	1	0.148	456	0.01	0.05	0.1	0.1	5.31	10.9	45.8	0.1	0.1	45.1	0.2
B4	1.5	A	7.69	0.347	1	0.129	463	0.01	0.05	0.1	0.1	7.88	17.9	43.3	0.109	0.1	41.6	0.2
B4	2.0	A	11.1	0.1	1	0.138	394	0.01	0.05	0.1	0.1	15.6	14.7	35.5	0.169	0.1	29.9	0.2
B4	2.5	A	6.22	0.1	1	0.135	520	0.01	0.05	0.1	0.1	4	39.2	55.1	0.1	0.1	77.7	0.2
B4	3.0	A	5.8	0.518	1	0.163	501	0.01	0.05	0.1	0.1	4.34	10.8	52.6	0.1	0.1	60.1	0.2
B4	3.5	A	5.53	0.139	1	0.131	523	0.01	0.05	0.1	0.1	1.9	17.9	47.5	0.1	0.1	68.6	0.2
B4	4.0	A	9.97	0.1	1	0.15	424	0.01	0.05	0.1	0.1	12.5	28.8	52.5	0.147	0.1	46.5	0.2
B4	4.5	A	6.42	0.1	1	0.132	368	0.01	0.05	0.1	0.1	7.54	18.1	35.7	0.121	0.1	23.2	0.2

Appendix B: Nutrient availability before and after phosphorus fertilizer addition (continued).

				P	Pb	Sb	Se	Si	Sr	V	Zn
				mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg
Block	**PO4 treatment**	**Time**	**Detection limits**	**0.1**	**0.2**	**0.2**	**0.1**	**1**	**0.2**	**0.1**	**0.1**
B1	0.5	B		0.1	0.2	0.2	0.1	5.41	2.11	0.1	0.116
B1	1.0	B		0.1	0.2	0.2	0.1	43.5	0.72	0.139	0.1
B1	1.5	B		0.1	0.2	0.2	0.1	6.58	1.6	0.1	0.1
B1	2.0	B		0.1	0.2	0.2	0.149	6.21	1.77	0.1	0.1
B1	2.5	B		0.1	0.2	0.2	0.1	10.5	0.988	0.1	0.1
B1	3.0	B		0.1	0.2	0.2	0.1	9.73	1.12	0.1	0.1
B1	3.5	B		0.1	0.2	0.2	0.328	6.66	2.5	0.1	0.1
B1	4.0	B		0.1	0.2	0.2	0.1	38.3	0.984	0.1	0.1
B1	4.5	B		0.1	0.2	0.2	0.394	5.82	3.11	0.1	0.1
B2	0.5	B		0.1	0.2	0.2	0.1	49.8	0.728	0.155	0.1
B2	1.0	B		0.1	0.2	0.2	0.1	16	1.78	0.1	0.1
B2	1.5	B		0.1	0.2	0.2	0.1	8.61	1.05	0.1	0.1
B2	2.0	B		0.1	0.2	0.2	0.282	15.4	1.08	0.1	0.1
B2	2.5	B		0.1	0.2	0.2	0.1	33.6	1.25	0.104	0.1
B2	3.0	B		0.1	0.2	0.2	0.1	7.08	1.6	0.1	0.1
B2	3.5	B		0.1	0.2	0.2	0.1	6.49	1.4	0.1	0.1
B2	4.0	B		0.1	0.2	0.2	0.1	8.89	1.02	0.1	0.1
B2	4.5	B		0.1	0.2	0.2	0.1	6.58	1.54	0.1	0.1
B3	0.5	B		0.1	0.2	0.2	0.1	11.1	0.953	0.1	0.1
B3	1.0	B		0.1	0.2	0.2	0.1	19.8	0.646	0.1	0.1
B3	1.5	B		0.1	0.2	0.2	0.1	7.11	1.23	0.1	0.1
B3	2.0	B		0.1	0.2	0.2	0.21	8.46	0.895	0.1	0.1
B3	2.5	B		0.1	0.2	0.2	0.1	10.3	0.921	0.1	0.1
B3	3.0	B		0.1	0.2	0.2	0.145	13.5	0.814	0.1	0.1
B3	3.5	B		0.1	0.2	0.2	0.1	11.8	1.14	0.1	0.1
B3	4.0	B		0.1	0.2	0.2	0.1	8.13	0.984	0.1	0.1
B3	4.5	B		0.1	0.2	0.2	0.1	6.09	1.44	0.1	0.1
B4	0.5	B		0.1	0.2	0.2	0.1	10.2	1.05	0.1	0.1
B4	1.0	B		0.1	0.2	0.2	0.1	15.7	0.678	0.1	0.1
B4	1.5	B		0.1	0.2	0.2	0.1	10.2	1.05	0.1	0.1
B4	2.0	B		0.1	0.2	0.2	0.1	14.7	0.823	0.1	0.1
B4	2.5	B		0.1	0.2	0.2	0.1	12.8	0.83	0.1	0.1
B4	3.0	B		0.1	0.2	0.2	0.1	7.09	1.07	0.1	0.1

B4	3.5	B	0.1	0.2	0.2	0.122	12.2	0.932	0.1	0.1
B4	4.0	B	0.1	0.2	0.2	0.1	31.2	0.853	0.1	0.1
B4	4.5	B	0.1	0.2	0.2	0.1	43	0.713	0.1	0.1
B1	0.5	A	0.1	0.2	0.2	0.241	7.56	1.2	0.1	0.156
B1	1.0	A	0.1	0.2	0.2	0.1	8.95	0.604	0.1	0.1
B1	1.5	A	0.1	0.2	0.2	0.285	7.12	1.57	0.1	0.1
B1	2.0	A	0.1	0.2	0.2	0.264	8.7	0.903	0.1	0.1
B1	2.5	A	0.1	0.2	0.2	0.1	23.5	0.737	0.1	0.1
B1	3.0	A	0.1	0.2	0.2	0.1	7.07	1.06	0.1	0.1
B1	3.5	A	0.1	0.2	0.2	0.1	6.64	3.12	0.1	0.1
B1	4.0	A	0.1	0.2	0.2	0.293	20.7	0.729	0.1	0.1
B1	4.5	A	0.1	0.2	0.2	0.1	7.11	1.71	0.1	0.1
B2	0.5	A	0.1	0.2	0.2	0.292	32.7	0.71	0.1	0.1
B2	1.0	A	0.1	0.2	0.2	0.116	8.79	1.84	0.1	0.1
B2	1.5	A	0.1	0.2	0.2	0.1	10.5	1.24	0.1	0.1
B2	2.0	A	0.1	0.2	0.2	0.401	8.35	0.996	0.1	0.683
B2	2.5	A	0.1	0.2	0.2	0.1	19.4	1.15	0.1	0.1
B2	3.0	A	0.1	0.2	0.2	0.213	9.77	1.1	0.1	0.1
B2	3.5	A	0.1	0.2	0.2	0.1	8.5	1.08	0.1	0.1
B2	4.0	A	0.1	0.2	0.2	0.1	8.2	1.28	0.1	0.106
B2	4.5	A	0.1	0.2	0.2	0.109	12.4	0.911	0.1	0.1
B3	0.5	A	0.1	0.2	0.2	0.1	16.6	0.583	0.1	0.1
B3	1.0	A	0.1	0.2	0.2	0.1	15.7	0.924	0.1	0.1
B3	1.5	A	0.1	0.2	0.2	0.1	18.9	0.82	0.1	0.1
B3	2.0	A	0.1	0.2	0.2	0.232	18.5	0.615	0.1	0.1
B3	2.5	A	0.1	0.2	0.2	0.1	22.8	0.621	0.1	0.1
B3	3.0	A	0.1	0.2	0.2	0.1	20	1.16	0.1	0.1
B3	3.5	A	0.1	0.2	0.2	0.1	9.83	1.11	0.1	0.1
B3	4.0	A	0.1	0.2	0.2	0.1	8.62	1.3	0.1	0.1
B3	4.5	A	0.1	0.2	0.2	0.1	10.6	2	0.1	0.1
B4	0.5	A	0.1	0.2	0.2	0.328	18.7	0.987	0.1	0.1
B4	1.0	A	0.1	0.2	0.2	0.262	19.3	0.704	0.1	0.1
B4	1.5	A	0.1	0.2	0.2	0.227	24.3	0.836	0.1	0.1
B4	2.0	A	0.1	0.2	0.2	0.1	33.1	0.688	0.1	0.1
B4	2.5	A	0.1	0.2	0.2	0.1	15.7	0.916	0.1	0.1
B4	3.0	A	0.1	0.2	0.2	0.1	14	0.773	0.1	0.1
B4	3.5	A	0.1	0.2	0.2	0.1	11.9	1.13	0.1	0.1
B4	4.0	A	0.1	0.2	0.2	0.1	34	0.685	0.1	0.1
B4	4.5	A	0.85	0.2	0.2	0.1	23.9	0.641	0.1	0.1