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FINAL REPORT
on
MOISTURE AND NUTRIENT DYNAMICS IN TRUEGRO SOIL CONDITIONER

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Executive Summary

A series of laboratory and greenhouse tests were conducted at the Texas A&M University Research and Extension Center in Dallas to determine some of the basic chemical and physical properties of TrueGro Soil Conditioner and to understand the basic dynamics of its interaction with water and nutrients.

Individual TrueGro aggregates were able to absorb 38% of their weight in water. When placed in contact with a saturated porous medium, TrueGro Soil Conditioner rapidly absorbed 15% water in 10 minutes and 20% water in less than 2 hours. Water that is rapidly absorbed is readily available to plants. When immersed in pure water, TrueGro Soil Conditioner increased pH of the water to above 8. However, the ability of TrueGro Soil Conditioner to neutralize acidity was less than 1% as effective as calcium carbonate. Consequently, when TrueGro Soil Conditioner is added to soil, there will be no net change in soil pH. TrueGro Soil Conditioner showed little indication of cation exchange capacity, but it contained trace amounts of plant available calcium, magnesium and potassium. The soluble salt content of TrueGro Soil Conditioner was low and poses no risk to plant growth.

Because TrueGro Soil Conditioner was able to absorb relatively large quantities of water, it also absorbed nutrients dissolved in that water. Fertilizer-impregnated TrueGro Soil Conditioner was extracted with water to determine if nutrients would be available to plants. Release of highly soluble nutrients, such as nitrate-nitrogen (NO_3-N) and ammonium-nitrogen (NH_4-N) was initially quite rapid, but later occurred at a slower rate. The major mechanism controlling their release from TrueGro Soil Conditioner was diffusion due to a concentration gradient. Less soluble phosphate-phosphorus (PO_4-P) was retained more strongly than NO_3-N and NH_4-N in the TrueGro Soil Conditioner medium, probably due to its adsorption and/ or precipitation on the surfaces of calcium and magnesium oxides. Consequently, phosphorus release from TrueGro Soil Conditioner exhibited a slow and constant trend. Lettuce was grown in the fertilizer-impregnated TrueGro Soil Conditioner to determine the bioavailability of adsorbed nutrients. The lettuce was able to extract and utilize nutrients from the fertilizer-treated TrueGro Soil Conditioner. Increasing the fraction of fertilizer-treated TrueGro Soil Conditioner in the growing medium resulted in dramatic increases in total plant yield and in uptake of nitrogen and phosphorus.

Current experimental results indicate that TrueGro Soil Conditioner has physical and chemical properties that would make it a beneficial component of plant growing media – whether it is soil, potting media or landscape mixtures.

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Introduction

TrueGro Soil conditioner is produced from expanded shale, an important material in the construction industry. However, it may have properties that also make it beneficial as a soil amendment for horticultural purposes. TrueGro soil conditioner is a lightweight, porous, inorganic material that is stable when mixed with soil. Therefore, it will have long-term effects on soil physical properties. The first step in considering a material as a soil amendment is to thoroughly understand its basic physical and chemical properties. The objective of study was to understand the dynamics of water and nutrient adsorption by TrueGro Soil Conditioner.

Materials and Methods

Basic chemical properties

pH and electrical conductivity: Untreated TrueGro Soil Conditioner was equilibrated with water to determine equilibrium pH. TrueGro Soil Conditioner was also equilibrated with a solution of 0.01 M $CaCl_2$ in order to minimize the possible effect on pH of variable background concentrations of dissolved elements. A separate sample of TrueGro Soil Conditioner was extracted with water in a ratio of 1:1 (w/ v) to determine electrical conductivity.

Soluble and labile elements: One part TrueGro Soil Conditioner was extracted with 10 parts of water to determine the concentration of soluble elements. Soluble elements are immediately available to plants and microbes when applied to soil, but they are also susceptible to leaching. A separate sample of TrueGro Soil Conditioner was extracted with a buffered acid solution (1 mole/ liter sodium acetate) to measure labile elements. Labile elements are not immediately soluble in water, but they are potentially available to plants and soil microorganisms when applied to soil.

Calcium carbonate equivalent: Calcium carbonate equivalent (CCE) is the measure of a material's ability to neutralize acidity relative to pure calcium carbonate. The comparison is useful for determining how a material will affect soil pH when mixed with soil. The CCE of TrueGro Soil Conditioner was estimated by equilibrating a known quantity of TrueGro Soil Conditioner with increasing amounts of acid (0.1 mole/ liter HCl) and measuring pH of the equilibrium mixture. The amount of acid used to obtain a neutral pH 7 was used to calculate the amount of pure $CaCO_3$ required to neutralize an equal amount of acidity. The CCE is the ratio of the calculated quantity of pure $CaCO_3$ to the actual quantity of TrueGro Soil Conditioner.

Water uptake

Water uptake experiments were designed to evaluate uptake and retention of water by individual aggregates of TrueGro Soil Conditioner rather than a bulk amount of the material.

The volume of water measured in this manner includes only the internal pores of each TrueGro Soil Conditioner aggregate. It should be noted that measuring the water holding capacity of a bulk volume of TrueGro Soil Conditioner would give a higher value because it would also include pore space between adjacent aggregates.

Maximum water holding content: To measure maximum water holding capacity of TrueGro Soil Conditioner, a quantity of TrueGro Soil Conditioner was submerged in water for 72 h in order to completely saturate individual aggregates. At the end of that time, TrueGro Soil Conditioner was removed from the water, weighed to determine saturated weight, and placed in an oven at 105°C for 48 hours. After all water had evaporated from the TrueGro Soil Conditioner, dry weight was measured, and together with the saturated weight, was used to calculate the maximum water holding capacity of TrueGro Soil Conditioner.

Water adsorption rate: Also of interest is the rate at which TrueGro Soil Conditioner can absorb water. For this experiment, a quantity of TrueGro Soil Conditioner was spread onto water-saturated filter paper. The filter paper was maintained in a saturated condition by the use of wicks. Water diffused into the TrueGro Soil Conditioner from the filter paper through the point of direct contact. TrueGro Soil Conditioner was left on the water-saturated filter paper for periods ranging from 2.5 minutes to 72 hours. After the specified time, TrueGro Soil Conditioner was removed from the filter paper and oven-dried to determine water content.

Bioavailability of adsorbed nutrients

Nutrient release from fertilizer-treated TrueGro Soil Conditioner: A quantity of pre-washed, TrueGro Soil Conditioner was saturated with a complete nutrient solution (2% solution of Peters 20-20-20). Upon removal from the nutrient solution, the TrueGro Soil Conditioner was rinsed with water to remove surficial layers of nutrient solution and then allowed to air dry. A separate quantity of untreated TrueGro Soil Conditioner was rinsed with distilled water to remove soluble nutrients inherent to the material. Untreated and nutrient-saturated TrueGro Soil Conditioner were mixed at ratios of 100:0, 75:25, 50:50, 25:75, and 0:100 percent. A known quantity of each TrueGro Soil Conditioner treatment (25 g) was extracted six consecutive times with water (40 mL water per extraction). Each sequential extract was analyzed for nutrient concentrations.

Lettuce growth in fertilizer-treated TrueGro Soil Conditioner: A bioavailability test was conducted to determine if plants were able to extract nutrients from the fertilizer-treated TrueGro Soil Conditioner. The various mixtures were placed in greenhouse pots, covered with a thin layer of acid-washed sand, and planted with Romaine lettuce. Plants received adequate water, but no additional nutrients were supplied. After one month, above ground plant tissue was harvested and dried to determine yield. Plant tissue was analyzed for macro- and microelements.

Results and Discussion

Basic chemical properties

pH

Table 1 shows pH values for TrueGro Soil Conditioner measured in water (ASTM D 4972-89) and in a 0.01 mole/ liter dilute $CaCl_2$ solution (McLean, 1982). The purpose of using $CaCl_2$ was to minimize pH differences due to variable background salt concentrations. The close agreement between the two values (pH 8.3 for water versus pH 8.5 for $CaCl_2$) indicates minimal effects due to soluble salts and suggests that both values accurately represent the pH of TrueGro Soil Conditioner.

The measured pH values for TrueGro Soil Conditioner reflect the presence of calcium, magnesium, potassium, and sodium oxides (CaO, MgO, K_2O, and Na_2O). These oxides are formed due to the high temperatures used to manufacture the expanded shale used in TrueGro Soil Conditioner. When TrueGro Soil Conditioner is exposed to water, these oxides hydrolyze to form hydroxides, which can raise pH to as high as 13 in the equilibrium solution. The fact that the equilibrium pH of the TrueGro Soil Conditioner tested in this study only increased to 8.3 suggests the presence of relatively small quantities of reactive oxides. Expanded shale materials with higher quantities of reactive oxides would have higher equilibrium pH values.

Calcium carbonate equivalent (CCE)

A material's capacity to neutralize acidity indicates its potential effect on pH when mixed with soil. The calcium carbonate equivalent (CCE) shows the material's effectiveness relative to lime (calcium carbonate), which is the standard for neutralizing soil acidity. The TrueGro Soil Conditioner analyzed in this study had a CCE of 0.2 to 0.3 percent. In other words, TrueGro Soil Conditioner is less than 1% effective at neutralizing soil acidity as calcium carbonate limestone and would have no measurable effect on soil pH.

Electrical conductivity (EC)

Electrical conductivity (EC) is an indirect measurement of the soluble salt concentration of a material. Research has shown that an EC of less than 2 dS/ m in soil will have negligible salinity effects on plant growth (Mengel and Kirkby, 1982). A 1:1 water extract of TrueGro Soil Conditioner had an EC of 1.6 dS/ m (Table 1). This value indicates that TrueGro Soil Conditioner will not create salinity problems when added to soil.

Soluble and labile elements:

TrueGro Soil Conditioner was extracted with water to measure the concentration of soluble elements and with acidified sodium acetate to measure potentially plant-available (labile) elements. Concentrations of water-soluble sodium (Na), potassium (K), magnesium (Mg), and calcium (Ca) in TrueGro Soil Conditioner were small and similar in magnitude (Table 1). This result is consistent with the low EC that was reported above. When TrueGro Soil Conditioner was extracted with acidified sodium acetate, only slightly higher amounts or Na and K were extracted, whereas the amounts of Mg and Ca were increased 20-fold and 10-fold respectively. The data suggests that the heating process used to manufacture the expanded shale in TrueGro Soil Conditioner produces small amounts of Na, K, Mg, and Ca salts that are easily soluble in water, plus larger amounts of Mg and Ca oxides that will dissolve in weak acid (pH 5). Potassium, Mg, and Ca are essential plant nutrients. Addition of TrueGro Soil Conditioner to soil will provide small amounts of immediately plant-available K, Mg, and Ca plus larger amounts of more slowly available Mg and Ca. However, it should be emphasized that when TrueGro Soil Conditioner is added to soil, the inherent concentrations of these elements are too low to significantly affect plant nutrition – either beneficially or detrimentally.

Water uptake

Two facets of water uptake by TrueGro Soil Conditioner were investigated: 1) the maximum water-holding capacity and 2) the rate of water uptake. The maximum water holding capacity provides information on the total porosity in TrueGro Soil Conditioner aggregates. After soaking in water for at least 72 hr, the TrueGro Soil Conditioner tested in our study contained 37.8% water (Table 1). This value includes the amount of water in TrueGro Soil Conditioner when 100% of the pores are saturated plus the small amount of water on the surface of the TrueGro Soil Conditioner aggregates. The water-holding capacity of TrueGro Soil Conditioner shows that it can be a significant source of water storage in soil. However, a typical silt loam soil will have a greater available water holding capacity than TrueGro Soil Conditioner. Therefore, TrueGro Soil Conditioner should be used as a soil amendment for soils that retain excess water and exhibit poor drainage characteristics.

The rate at which TrueGro Soil Conditioner can absorb water is perhaps more important than its total water holding capacity. The water uptake rate provides information on the size of pores in the TrueGro Soil Conditioner aggregate and can be related to the amount of water that will be available to plants. Figure 1 shows that TrueGro Soil Conditioner absorbed 15% of its weight in water within 10 minutes and 20% within 2 hours. The water uptake rate slows considerably beyond 2 hours, but continued to increase to a maximum of 36% at 150 hours. The experiment was designed so that water could only enter the TrueGro Soil Conditioner aggregates via capillary diffusion. When a TrueGro Soil Conditioner aggregate was placed in contact with a saturated porous media, water quickly diffused throughout the aggregate's surface layer until it appeared the aggregate was saturated. However, gravimetric measurements showed that the TrueGro Soil Conditioner aggregates continued to absorb water for up to 150 hours. It appears the largest pores in TrueGro Soil Conditioner are located near the surface of the aggregates and smaller pores are located more towards the center.

The water uptake curve shown in Fig. 1 suggests that if TrueGro Soil Conditioner is present in soil or some other growing media, and water is added to that media through rainfall or irrigation, TrueGro Soil Conditioner will quickly absorb water and retain it for plant use. In terms of water availability to plants, it is likely that 15 to 20% of the water in TrueGro Soil Conditioner is easily available to plants. This represents the amount of water easily absorbed by TrueGro Soil Conditioner over a relatively short period of time (<2 hr). The actual quantity of plant available water would depend on the type of plant.

Bioavailability of adsorbed nutrients

Nutrient release from fertilizer-treated TrueGro Soil Conditioner

The porous nature of TrueGro Soil Conditioner allows it to absorb water and chemical constituents dissolved in the water. For this experiment, TrueGro Soil Conditioner was soaked in a 2% solution of Peter's water-soluble fertilizer (20-20-20) for 48 hours, rinsed three times in deionized water, and air-dried. The fertilizer-impregnated TrueGro Soil Conditioner was rinsed in water to ensure that nutrients released from the aggregates were from the internal pores and not residual surface deposits of fertilizer. Based on results from the water uptake experiment (Fig. 1), 5 to 10% of the pore volume was not saturated with fertilizer solution because the TrueGro Soil Conditioner was soaked for only 48 hours. Also, it is likely that 10 to 15% of the fertilizer was removed from the TrueGro Soil Conditioner during the rinsing process. These two factors probably reduced the total nutrient-supplying capacity of the fertilizer-treated TrueGro Soil Conditioner 15 to 25%.

A portion of each fertilizer-treated TrueGro Soil Conditioner medium was sequentially extracted with water to determine the kinetics of nutrient release. Nutrients extracted with water are immediately available for plant uptake. Nitrate-nitrogen (NO_3-N), ammonium-nitrogen (NH_4-N), and phosphate-phosphorus (PO_4-P) were measured in all extracts. In general, the concentration of each constituent decreased with each sequential extract (Fig. 2). This demonstrates that a portion of soluble nutrients absorbed by TrueGro Soil Conditioner can later redissolve and become available for plant uptake. If TrueGro Soil Conditioner were present in a growing medium, individual aggregates would either absorb or release nutrients depending on the concentration gradient with the surrounding solution. In practical terms, if pure water passed through the growing medium, TrueGro Soil Conditioner would release nutrients into the surrounding solution where the nutrient concentration was lower. If a nutrient solution passed through the medium, nutrients would possibly diffuse into the TrueGro Soil Conditioner aggregates in response to the nutrient gradient.

Nitrate-nitrogen, NH_4-N and PO_4-P each have different binding mechanisms to solid particles in a growing medium. Nitrate-nitrogen has a negative charge and exists as a free (i.e., unbound) ion in typical soil conditions. It moves freely through the soil with soil water. Ammonium-nitrogen has a positive charge and is attracted to negatively charged exchange sites found in typical soils. This allows it to be held more tightly in the soil and makes it less susceptible to loss through leaching. Phosphate-phosphorus is called an ox anion. It has a negative charge, but unlike NO_3-N, it tends to strongly bind to various soil components, primarily aluminum, iron, and calcium containing minerals.

The different chemistries of NO_3-N, NH_4-N, and PO_4-P were apparent in the sequential extraction data presented in Fig. 2. Nitrate-N was easily extracted with water. This was best illustrated with the 100% fertilizer-treated TrueGro Soil Conditioner treatment. The first extraction removed 100 mg NO_3-N per kg of TrueGro Soil Conditioner. By the fourth extraction, the amount extracted had decreased to 7 mg/ kg, but was still slightly greater than the concentration for the control (i.e., TrueGro Soil Conditioner without fertilizer pre-treatment). The remaining extractions continued to remove small amounts of NO_3-N that were slightly greater than the control. The extraction of NO_3-N from fertilizer-treated TrueGro Soil Conditioner was consistent with water uptake data that showed very rapid water uptake followed by a much slower uptake phase (Fig. 1). In the absence of any attractive force between NO_3-N and the TrueGro Soil Conditioner aggregate, NO_3-N would diffuse out of the TrueGro Soil Conditioner in a similar fashion to water. The rapid release of NO_3-N with the initial extractions corresponds to diffusion of NO_3-N from larger pores near the surface of the aggregate. The much lower, yet significantly higher concentrations of NO_3-N released with the later extractions relative to the control suggest diffusion of NO_3-N from smaller pores deeper inside the TrueGro Soil Conditioner aggregate.

Smaller amounts of NH_4-N were extracted from fertilizer-treated TrueGro Soil Conditioner compared to NO_3-N because the fertilizer source contained a larger concentration of the latter. Other than quantity extracted, release of NH_4-N from fertilizer-treated TrueGro

Soil Conditioner followed a trend similar to that shown by NO_3-N. The cation exchange capacity (CEC) of TrueGro Soil Conditioner (Table 1) was too low to retain a significant amount of positively-charged NH_4-N cations. Therefore, the mechanism for removal of NH_4-N from fertilizer-treated TrueGro Soil Conditioner was essentially the same as for NO_3-N, i.e., diffusion out of the aggregate in response to a concentration gradient.

Phosphorus release curves from fertilizer-treated TrueGro Soil Conditioner were distinct from those for NO_3-N and NH_4-N (Fig. 2). The amount of PO_4-P released decreased linearly with each successive extraction. There was no rapid release with the initial extractions as seen for NO_3-N and NH_4-N. This suggests that other factors, in addition to diffusion, controlled the release of PO_4-P from TrueGro Soil Conditioner. The presence of calcium oxides and magnesium oxides in TrueGro Soil Conditioner create conditions favorable to the adsorption and/ or precipitation of PO_4-P. Experience with calcareous soils has shown that dicalcium phosphate ($CaHPO_4$) is commonly a first precipitation product following application of phosphate fertilizer (Sposito, 1989). Although no calcium carbonates are present in TrueGro Soil Conditioner, its high pH and soluble Ca characteristics make it analogous to high pH soils and suggests the possible precipitation of the relatively soluble dicalcium phosphate ($CaHPO_4$) mineral. Phosphate adsorption and precipitation are reversible processes, particularly in a TrueGro Soil Conditioner medium, which is much less complex than a soil medium. Dissolution and release of adsorbed and precipitated phosphorus from TrueGro Soil Conditioner would occur at a slower and more constant rate than would be expected from simple diffusion due to a concentration gradient. The practical implication of these results is that phosphorus-impregnated TrueGro Soil Conditioner could function as a relatively effective slow-release phosphorus fertilizer.

Lettuce growth in fertilizer-treated TrueGro Soil Conditioner

The true test of nutrient bioavailability is whether plants are able to extract and utilize nutrients from the growing medium. For this experiment, Romaine lettuce was grown in the same fertilizer-treated, TrueGro Soil Conditioner mediums that were described in the preceding sequential extraction discussion. Briefly, the growing media consisted entirely of TrueGro Soil Conditioner where an increasing fraction of the TrueGro Soil Conditioner medium was previously impregnated with fertilizer solution. The percentage of fertilizer-treated TrueGro Soil Conditioner ranged from 0 to 100%. Lettuce was grown for approximately 45 days with no additional fertilizer application and then harvested to determine shoot and root yields. Aboveground tissue was analyzed for total nitrogen and phosphorus. Results for this experiment are shown in Fig. 3.

The quantity of aboveground lettuce shoots increased linearly as the percentage of fertilizer-treated TrueGro Soil Conditioner in the growing medium was increased (Fig. 3). Root mass also increased with increasing proportion of fertilizer- treated TrueGro Soil Conditioner, but reached a maximum at the 75% fraction. Total uptake of nitrogen and phosphorus also increased linearly with increasing proportion of fertilizer-treated TrueGro Soil Conditioner (Fig. 3). The yield and nutrient uptake data demonstrate that nutrients in the fertilizer-treated TrueGro Soil Conditioner medium were taken up and assimilated by plants. The level of fertility was sufficient to support lettuce growth for approximately 45 days with no additional fertilization.

References

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Table 1. Basic chemical and physical properties of TrueGro Soil Conditioner. Standard deviation on the mean is shown in parentheses.

Parameter	**Measured Value** Mean	SD†
pH		
(1:1 – water)	8.25	(± 0.62)
(1:1 – 0.01 M $CaCl_2$)	8.47	(± 0.21)
Calcium carbonate equivalent (CCE), %	0.2 – 0.3	
Electrical conductivity, dS/ m	1.6	(± 0.2)
Water holding capacity, %	37.8	(± 1.35)
Cation exchange capacity (CEC), cmole kg^{-1}	2.75	(±0.15)
Extractable elements, mg/ kg		
Water soluble		
Sodium (Na)	55.0	(± 6.5)
Potassium (K)	64.2	(± 6.0)
Magnesium (Mg)	29.0	(± 2.8)
Calcium (Ca)	88.3	(± 10.6)
Acid soluble§		
Sodium (Na)	87.3	(± 5.3)
Potassium (K)	126.8	(± 21.0)
Magnesium (Mg)	660	(± 40)
Calcium (Ca)	843	(± 59)

† Standard deviation of the mean.

§ 1 mole/ liter Sodium Acetate buffered to pH 5 with Acetic Acid.

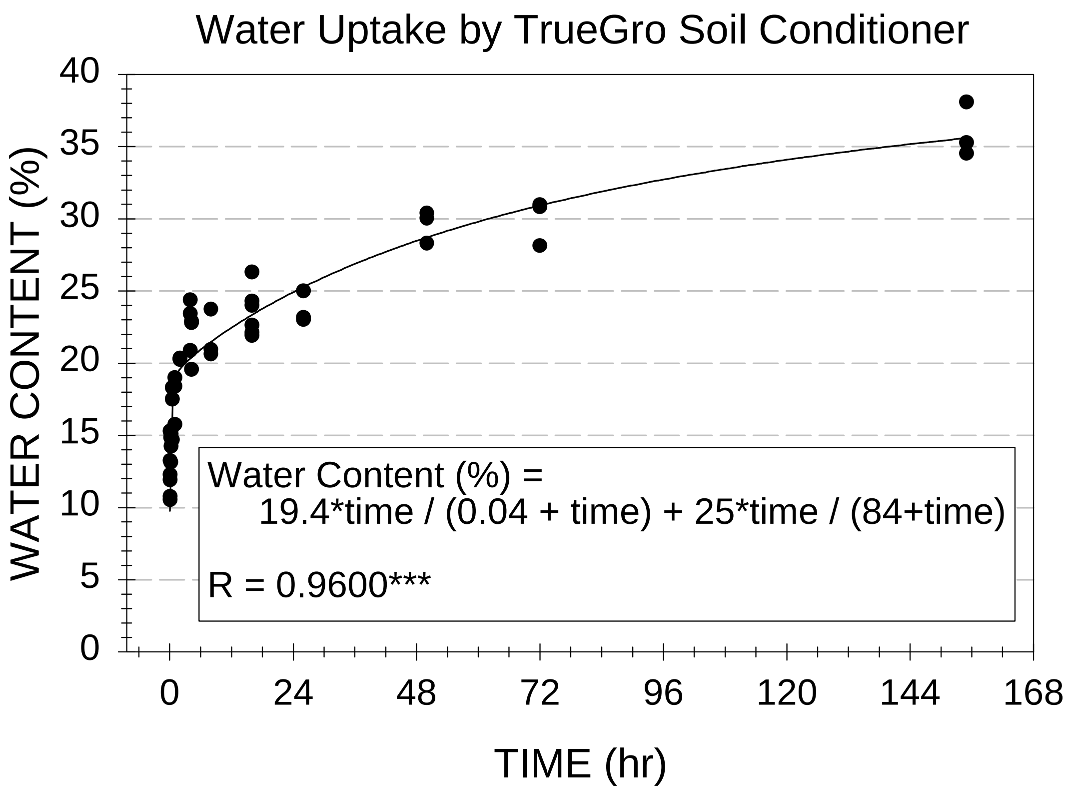

Fig. 1. Rate of water diffusion into TrueGro Soil Conditioner. Data was fitted to a double rectangular hyperbolic function to create a predictive uptake equation. *** Significant at the 0.001 level of probability.

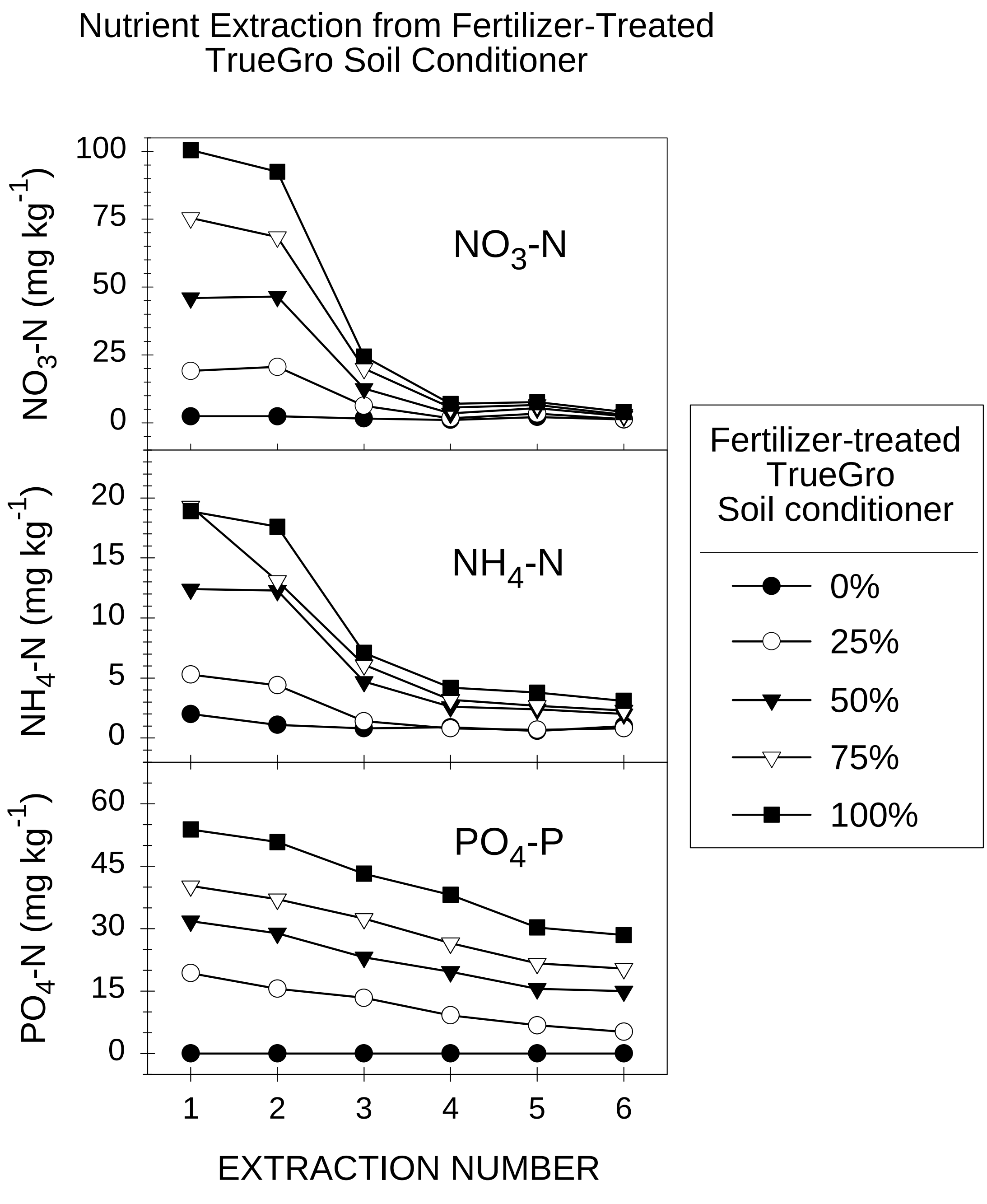

Fig. 2. Sequential extraction of nitrate-nitrogen, ammonium-nitrogen, and phosphate-phosphorus from fertilizer-treated TrueGro Soil Conditioner used as a growing medium.

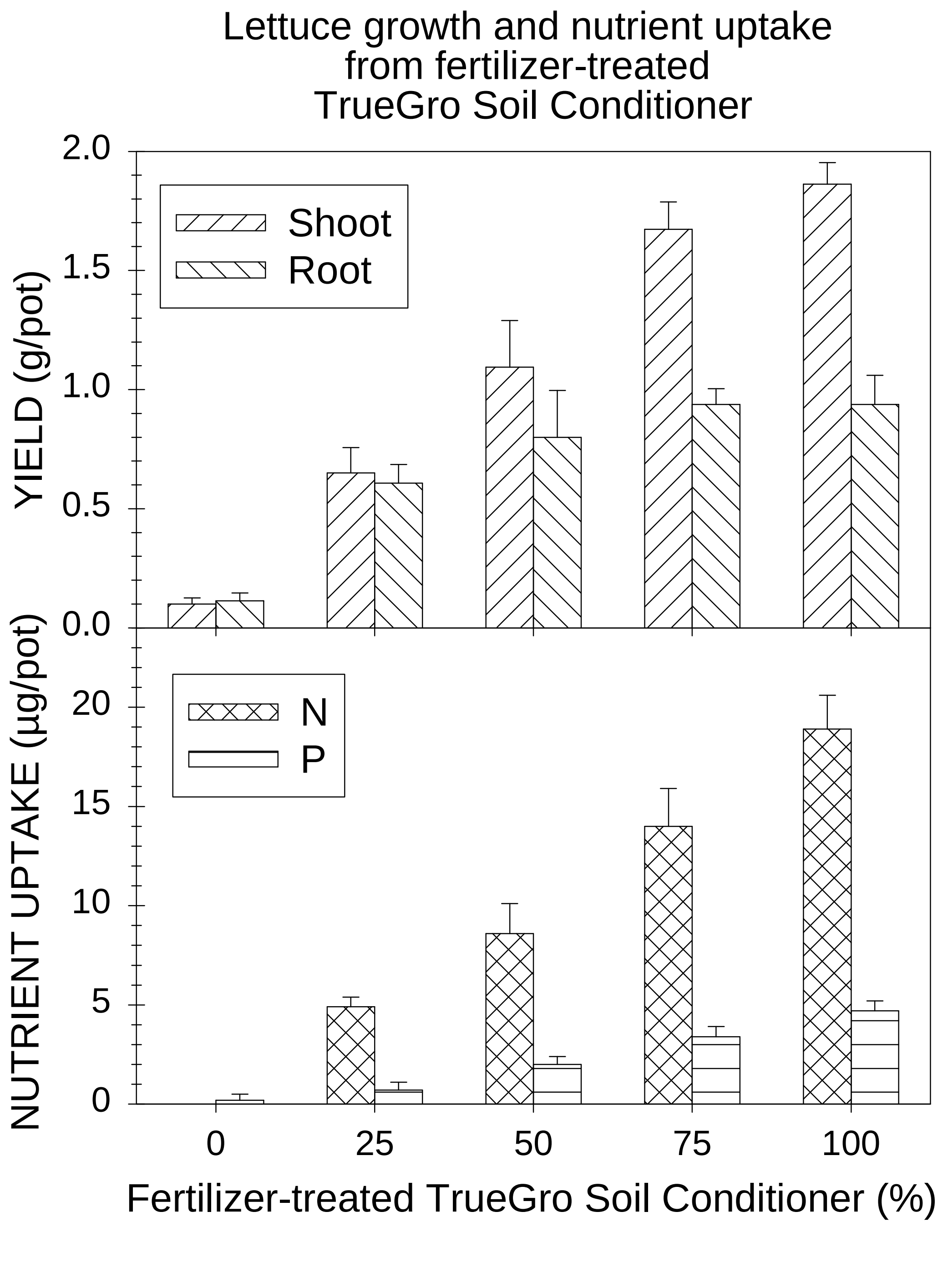

Fig.3. Lettuce yields and total nutrient uptake for lettuce grown in fertilizer-treated TrueGro Soil Conditioner.