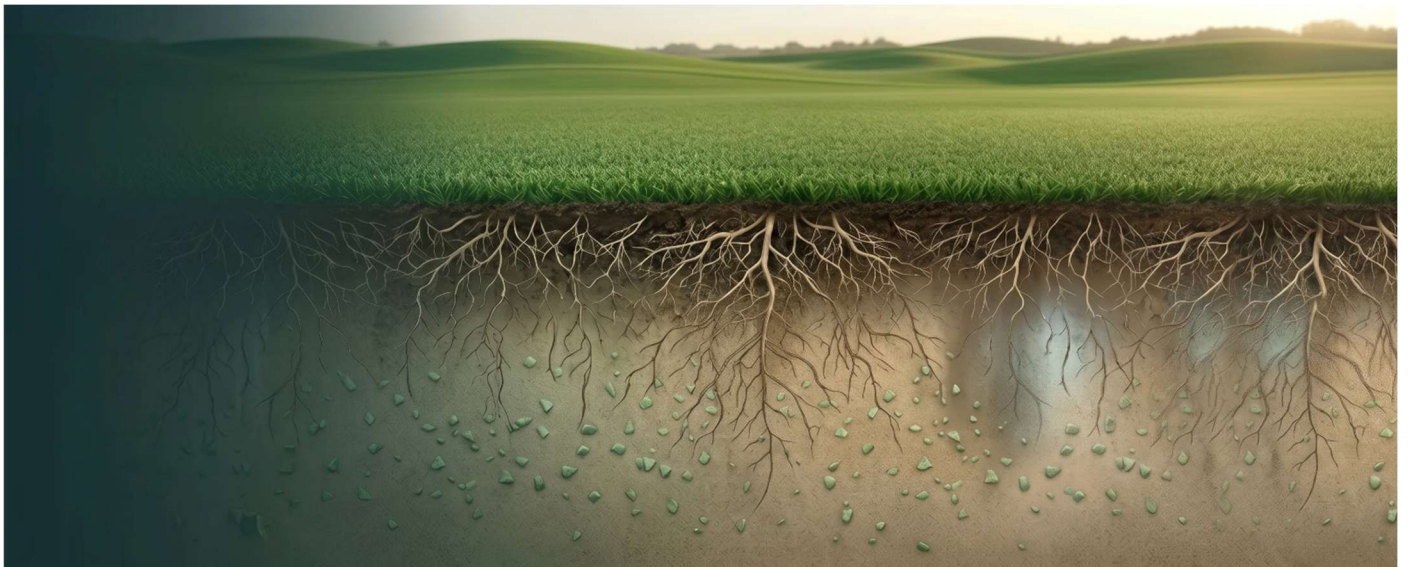


# Natural Zeolite in Engineered Soils and Root Zones

## Improving Nutrient Efficiency, Water Utilization, and Root Zone Performance in Agriculture, Golf, Sports Turf, and Horticulture

By F. L. Bunger, PhD  
ZEO, Inc. (zeoinc.com)



### Introduction

Modern agriculture, turfgrass management, and engineered root-zone systems increasingly require technologies that maintain high plant performance under growing environmental and economic pressures. Rising fertilizer costs, tightening water restrictions, nutrient runoff concerns, and declining soil efficiency have intensified interest in materials that improve nutrient retention, hydraulic stability, fertilizer utilization efficiency, and irrigation performance.

Many agricultural and engineered root-zone systems suffer from:

- low nutrient retention,
- poor water-holding capacity,
- rapid nutrient leaching,
- hydraulic instability, and
- inefficient fertilizer utilization.

These challenges are especially significant in:

- sandy agricultural soils,
- golf course putting greens,
- sports turf systems,
- greenhouse media,
- sod production, and
- engineered landscape root zones.

Clinoptilolite-rich natural zeolite has received increasing attention because its crystalline aluminosilicate structure provides:

- high cation exchange capacity (CEC),
- selective nutrient adsorption,
- nutrient buffering,
- water retention capability, and

EcoSand natural zeolite was developed for use in engineered root-zone systems where nutrient retention, hydraulic

performance, moisture buffering, and long-term root-zone stability are important performance considerations.

Natural zeolite functions as a dynamic ion-exchange reservoir, adsorbing, storing, and gradually releasing essential nutrient cations such as potassium and ammonium while also improving moisture retention in the root zone.

Unlike soluble fertilizers that may rapidly leach beyond the active root zone, zeolite-bound nutrients remain available for gradual plant uptake over extended periods [3,16,17].

Research involving agricultural systems, university turfgrass programs, engineered root zones, and NASA zeoionic technologies demonstrates the significant potential of natural zeolite for improving fertilizer efficiency, hydraulic performance, nutrient retention, and water utilization [16,17,20].

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## Engineered Root-Zone Systems and the Low CEC Problem

Modern engineered root-zone systems commonly utilize highly sand-based media because of their superior drainage, infiltration, and aeration characteristics. However, silica sand has an inherently low cation exchange capacity (CEC), poor nutrient retention, and limited moisture buffering capacity.

As a result, engineered sand systems are often prone to:

- potassium leaching,
- nitrogen inefficiency,
- rapid nutrient fluctuations,
- moisture instability,
- increased irrigation sensitivity, and
- reduced fertilizer utilization efficiency.

Research conducted by Travis Shaddox at the University of Florida identified low nutrient retention and poor water retention as major limitations of sand-based putting green systems [1].

The dissertation further reported that zeolite incorporation substantially increased cation exchange capacity and improved nutrient retention characteristics in sand-based root zones [1].

Clinoptilolite contains a permanent negative structural charge created by aluminum substitution within the crystal lattice. This negative charge is balanced by exchangeable cations such as:

- potassium,
- ammonium,
- calcium,
- magnesium, and
- sodium.

These cations may be reversibly exchanged with nutrients present in the soil solution [2,3,34].

This dynamic ion-exchange behavior allows EcoSand natural zeolite to function as a long-term engineered nutrient-buffering system capable of stabilizing nutrient concentrations within highly permeable root zones.

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## Potassium Retention, Root-Zone Buffering, and Plant Stress Management

Potassium is one of the most important plant macronutrients and plays a major role in:

- water regulation,
- stomatal control,
- root development,
- heat tolerance,
- drought resistance,
- disease resistance,
- and overall plant stress management [24,25].

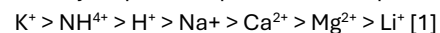
Potassium management is especially important in:

- sandy agricultural soils,
- golf course putting greens,
- sports turf systems,
- sod production,
- and highly drained engineered root zones.

Because these systems possess low native cation exchange capacity, potassium fertilizers may rapidly leach beyond the active root zone before efficient plant uptake occurs [11,30].

Clinoptilolite exhibits exceptionally strong selectivity for potassium ions (K<sup>+</sup>) [1,32].

The ion selectivity sequence reported for clinoptilolite is:



This selective ion-exchange behavior allows EcoSand natural zeolite to retain potassium within the root zone while gradually releasing potassium back into solution as plants absorb potassium during growth.

Importantly, the potassium is not permanently bound within the mineral structure. Instead, equilibrium shifts continuously regulate potassium availability within the soil solution.

Potential benefits include:

- reduced potassium leaching,
- improved potassium retention,
- improved fertilizer utilization efficiency,
- more stable root-zone potassium concentrations,

- improved drought tolerance,
- improved root development, and
- enhanced plant stress resistance [4,9,13,14].

These characteristics may be especially valuable in:

- golf course greens,
- sports turf systems,
- sod production,
- greenhouse production, and
- sandy agricultural soils.

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## Potassium vs. Sodium Form Natural Zeolite

The exchangeable cations naturally associated with clinoptilolite significantly influence zeolite performance in soil systems.

Clinoptilolite deposits commonly occur in:

- potassium-dominant form,
- sodium-dominant form, or
- calcium-dominant form.

For agricultural and engineered turfgrass applications, potassium-based zeolites are generally preferred because potassium is an essential plant nutrient while excessive sodium may negatively influence soil structure and root-zone chemistry [24,25].

Potassium-form EcoSand natural zeolite may provide several important agronomic and hydraulic advantages:

- supplemental slow-release potassium availability,
- reduced sodium loading,
- improved nutrient balance,
- improved fertilizer efficiency,
- improved root-zone compatibility,
- and improved hydraulic stability.

In contrast, sodium-form zeolites may release sodium into the soil solution during ion exchange reactions. Excessive sodium accumulation may contribute to:

- soil dispersion,
- reduced infiltration,
- reduced soil structure stability,
- salinity stress, and
- reduced plant performance under stress conditions.

Potassium-form clinoptilolite, therefore provides dual functionality by simultaneously acting as a high-CEC nutrient reservoir and as a supplemental potassium source.

EcoSand natural zeolite contains approximately 2% naturally occurring soluble potash, which may contribute supplemental

potassium availability while simultaneously functioning as a high-CEC nutrient-buffering material.

NASA zeoponic research further demonstrated the ability of potassium-exchanged clinoptilolite to function as a controlled nutrient source in engineered plant-growth systems [20].

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## Ammonia Retention and Nitrogen Utilization

Nitrogen loss represents one of the largest inefficiencies in modern fertilizer programs.

Ammonium fertilizers may undergo:

- volatilization,
- nitrification,
- denitrification,
- or leaching

before efficient plant uptake occurs.

Clinoptilolite exhibits strong selectivity for ammonium ions ( $\text{NH}_4^+$ ), allowing EcoSand

-amended soils and root zones to function as temporary ammonium reservoirs [1,5,6,7].

Research reviewed by Travis Shaddox demonstrated reduced ammonium and nitrate leaching in zeolite-amended sands [1].

As plants remove ammonium from the soil solution, equilibrium shifts gradually release zeolite-bound ammonium back into the root zone.

This controlled nutrient-release behavior may contribute to:

- reduced nitrogen leaching,
- improved fertilizer utilization efficiency,
- extended nitrogen availability,
- and improved root-zone nutrient stability [5,6,7,8,17].

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## Phosphorus Utilization and Reduced Phosphate Fixation

Many agricultural and turfgrass soils contain significant quantities of phosphorus that are not readily available for plant uptake because phosphate becomes chemically fixed by calcium, iron, and aluminum compounds.

As a result, soils may contain high total phosphorus concentrations while still exhibiting poor phosphorus availability and inefficient fertilizer utilization.

Although clinoptilolite does not strongly adsorb phosphate directly, natural zeolite may improve phosphorus utilization

indirectly through ion exchange and root-zone nutrient buffering [16,18].

Continuous exchange reactions involving calcium, potassium, magnesium, and ammonium may influence equilibrium conditions in the soil solution and help shift portions of previously unavailable phosphorus toward more soluble, plant-available forms.

In practical terms, EcoSand natural zeolite may help solubilize portions of fixed phosphorus already present in the soil, improving phosphorus utilization efficiency and potentially reducing supplemental phosphorus fertilizer requirements.

Potential benefits include:

- improved phosphorus utilization efficiency,
- increased availability of residual soil phosphorus,
- reduced phosphate fixation,
- improved nutrient synchronization,
- and reduced phosphorus fertilizer demand.

Research conducted at the University of Florida demonstrated that zeolite-amended systems influenced phosphorus breakthrough curves and phosphorus movement through sand systems [1].

NASA zeoponic research also demonstrated that clinoptilolite, combined with phosphate-containing minerals, could serve as controlled nutrient reservoirs that support multiple plant growth cycles with minimal external nutrient additions [20].

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## Hydraulic Conductivity, Water Retention, and Root-Zone Stability

One of the primary engineering challenges in high-performance root-zone systems is maintaining an appropriate balance between:

- drainage,
- infiltration,
- aeration,
- moisture retention,
- and nutrient availability.

Highly sand-based systems provide excellent infiltration and aeration characteristics but often exhibit poor water retention and limited nutrient buffering capability. Conversely, some amendments may improve water retention while negatively affecting hydraulic conductivity or long-term root-zone stability.

Research conducted by Travis Shaddox at the University of Florida evaluated hydraulic characteristics of amended sand-based putting green systems, including:

- saturated hydraulic conductivity,
- moisture retention,
- porosity, and
- water-use efficiency [1].

The research demonstrated that zeolite-amended root zones may improve plant-available water and nutrient retention while maintaining acceptable hydraulic performance for engineered sand systems.

Unlike many organic amendments that gradually decompose over time, clinoptilolite is a stable crystalline mineral capable of maintaining long-term physical and hydraulic stability within engineered root zones [1,17].

Potential hydraulic and physical benefits may include:

- improved moisture retention,
- improved plant-available water,
- improved root-zone buffering,
- reduced moisture fluctuations,
- maintained infiltration performance,
- improved nutrient retention,
- and long-term root-zone stability.

These characteristics are particularly important in:

- golf course putting greens,
- sports turf systems,
- sand-based athletic fields,
- engineered landscape systems, and
- highly permeable agricultural soils.

EcoSand natural zeolite was specifically developed for engineered systems requiring balanced hydraulic conductivity, nutrient buffering, moisture retention, and long-term root-zone stability.

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## Water Utilization and Drought Resistance

Water management has become one of the defining challenges in agriculture, turfgrass management, and engineered landscape systems.

Increasing water costs and irrigation restrictions have intensified interest in technologies that improve moisture retention and irrigation efficiency.

The porous internal structure of clinoptilolite enables the mineral to adsorb and retain substantial amounts of water while maintaining the aeration characteristics necessary for healthy root development [12,16,17].

Research by Travis Shaddox specifically investigated water-use efficiency (WUE) in amended USGA putting greens [1].

The dissertation concluded that soil amendments are commonly used to:

- increase plant available water,
- increase cation exchange capacity,
- and improve nutrient availability [1].

EcoSand-amended root zones may demonstrate:

- increased water-holding capacity,
- reduced irrigation frequency,
- improved drought resistance,
- reduced plant moisture stress,
- improved moisture stability, and
- enhanced nutrient buffering during drought periods.

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## Engineered Turfgrass Applications

Natural zeolite technologies have potential applications in:

- golf course putting greens,
- sports turf systems,
- sand-based athletic fields,
- sod production,
- greenhouse systems,
- engineered landscapes, and
- sandy agricultural soils.

EcoSand natural zeolite has been incorporated into engineered putting green systems at Punta Cana Resort & Club, host site of the Corales Punta Cana Championship.

These highly engineered sand-based systems require careful management of:

- hydraulic conductivity,
- nutrient retention,
- moisture stability,
- root-zone chemistry,
- and long-term turf performance.

The use of EcoSand® natural zeolite in these systems demonstrates the practical application of engineered mineral technologies in high-performance turf environments.

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## Conclusion

Clinoptilolite-rich EcoSand natural zeolite is a multifunctional engineered mineral technology that improves nutrient efficiency, hydraulic performance, water utilization, and root-zone

stability across a wide range of agricultural, turfgrass, horticultural, and engineered soil systems.

Its high cation exchange capacity and selective ion-exchange behavior enable EcoSand to serve as a dynamic nutrient reservoir, retaining and gradually releasing key plant nutrients such as potassium and ammonium while also improving moisture retention and hydraulic stability.

Research involving university turfgrass programs, engineered root zones, agricultural systems, and NASA zeoponic technologies demonstrates the significant potential of natural zeolite for improving fertilizer efficiency and long-term root-zone performance.

As agriculture and turfgrass management continue seeking methods to improve nutrient efficiency, reduce fertilizer losses, conserve water, and maintain high-performance engineered root zones, EcoSand® natural zeolite technologies are likely to play an increasingly important role in modern soil and root-zone management systems.

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## Suggested Citation

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