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Zeolite Application in Crop Production:
Importance to Soil Nutrient, Soil Water, Soil Health, and Environmental Pollution Management

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Introduction

According to the United States Geological Service (USGS), zeolites (Fig. 1) are hydrated aluminosilicates of alkaline and alkaline-earth metals with very porous structure. Zeolites are used as pet litter, in animal feed, in wastewater treatment, and as soil amendments. Identified about 200 years ago, there are over 40 different types that include analcime, chabazite, clinoptilolite, erionite, ferrierite, heulandite, laumontite, mordenite, and phillipsite. Those commonly used in crop production as soil conditioners are clinoptilolite, erionite, and mordenite. Zeolites are mostly present in soils and sediments, with clinoptilolite as the most abundant type. In 2019, the United States had nine zeolite mines producing an estimated 98,000 tons of natural zeolites, a 14% increase from 2018. Chabazite is mined in Arizona (Hyde, 1982; Flanagan, 2020) and clinoptilolite in New Mexico (Hyde, 1982). Although reported to have benefits as soil conditioners and growth media, these are less common than other uses. This bulletin gives a summary of the benefits of zeolite soil conditioners with respect to nutrient management and water retention, provides suggested application rates, and discusses challenges associated with the use of zeolite soil conditioners.

Benefits of zeolites as a soil conditioner and growth media

Zeolite soil conditioners or amendments may provide many benefits such as improved water infiltration and reduced surface water run-off and nutrient leaching (Fig. 2). Benefits from zeolite application could translate to increased yield, more efficient use of nutrient inputs, and reduction in environmental pollution of nitrogen (N) and phosphorus (P) in bodies of water, as well as reduction in greenhouse gas emissions (Fig. 2). The high cation exchange capacity (CEC) and porosity of zeolites allows them to absorb and trap greenhouse gases such as methane (CH_4) and carbon dioxide (CO_2).

Effects of zeolites on soil physical properties and soil water holding capacity

The high porosity of zeolite structure helps improve soil structure and increase aeration without clogging soil pores. Because of their porous nature zeolites can hold more than their weight in water, and in soil can act as a reservoir providing a prolonged water supply. Zeolites can improve water infiltration into soil, and speed re-wetting and lateral spread of irrigation water in the root zone (Nahkli et al., 2017).

Figure 1: Zeolite (clinoptilolite) in different particle sizes.

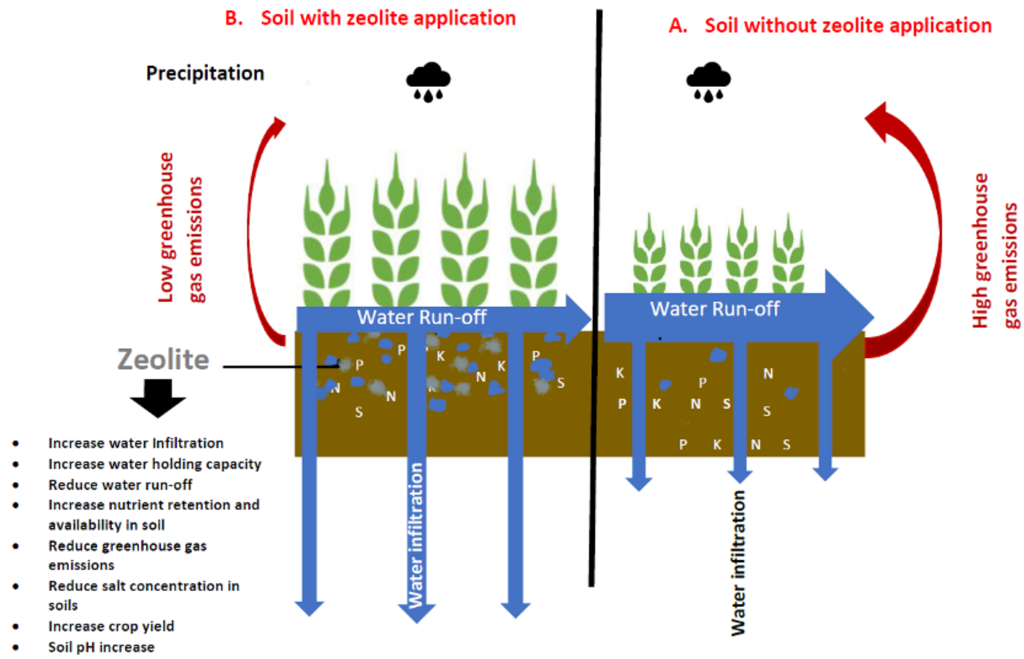

Figure 2: Benefits associated with using zeolites as a soil conditioner/amendment. A-left (soil with zeolite application) and B-right (soil without zeolite application). The red arrows show potential effects of zeolites on greenhouse gas emissions levels (a thicker arrow means more emissions). The black dots and arrows represent water, while the grey dots represent zeolite (modified from Nahkli et al., 2017).

Improved soil water holding capacity (WHC) is important for crop production, especially in arid and semi-arid regions where it increases water efficiency from irrigation. For example, soil treatment with the zeolite mordenite, which has a WHC of 121% (holding 1.21 times its own weight in water), increased soil water infiltration by 7-30% on a gentle slope and up to 50% on a steep slope, and reduced run-off after precipitation (Xiubin and Zhanbin, 2001). Also, mixing clinoptilolite, another zeolite, at a rate of 10% by weight to a sandy soil resulted in a 20% increase in WHC compared to untreated soil (Bigelow et al., 2001). Zeolite application could be combined with irrigation technology for improved water use efficiencies in the field, especially in dry regions (Mpanga and Idowu, 2020).

Effects of zeolites on soil nutrient availability to plants

Due to the high porosity and CEC of zeolites, they are able to increase soil CEC, therefore increasing soils' ability to capture and hold nutrients such as ammonium (NH_4^+) and potassium (K^+). Naturally occurring zeolites have very high CEC ranging from 100 to 200 $cmol_c$/kg (Inglezakis et al., 2015; Ming and Allen, 2001). This is roughly five to ten times that of typical Arizona soils. Zeolites can also act as slow-release agents for NH_4^+ and urea, which reduces nitrification and subsequent nitrogen loss, and retains nitrogen in the plant root zone longer. Incorporation of 10% (by weight) of clinoptilolite with ammonium sulfate reduced leaching of ammonium by 99% (Huang and Petrovic, 1994). In another study, 5% by weight of two zeolites (erionite and clinoptilolite) were added to loamy sand and fertilized with 200 mg/kg of ammonium sulfate. When the soils were leached with water, ammonium leaching in the soil amended with erionite was reduced by 93%, and by 83% in the clinoptilolite amended soil (MacKown and Tucker, 1985).

Effects of zeolites on soil health and environmental pollutant management

Zeolites could improve soil health indirectly by increasing soil water infiltration, improving soil structure, and reducing erosion and nutrient leaching. Zeolites can reduce pollution risks to water bodies by capturing and holding contaminants in their porous structure. Zeolite application can reduce ammonia (NH_3) gas emissions during composting by capturing and holding NH_4^+, and preventing it from converting to NH_3, which is a volatile greenhouse gas (Madrini et al., 2016; Wang et al., 2012). In Arizona, manure use increased by 30% from 2012 to 2017 (Mpanga et al., 2020), so integrating zeolites into manure and compost applications in fields could be a sustainable way to manage losses, reduce associated pollutants, and improve soil health.

Yield increase

Yield increases in crops as a result of zeolite application with either synthetic or organic fertilizers are reported in many crops, which could be associated with the benefits of improved soil structure, soil WHC, and enhanced soil nutrient conditions. For example, Aghaalikhani et al. (2011)

added clinoptilolite to canola growing in sandy loam fertilized with 240 lb/ac of nitrogen in the form of urea. Canola planted in soils receiving 1.35, 2.7, or 4.05 tons/acre showed 2.9%, 8.3%, or 29.3% higher seed yields when compared to canola growing in unamended soil. However, soil amendment costs may be high as the current market price of zeolites is $50 to $300 per ton (USGS, 2020).

Zeolite application in the field

Many factors such as soil texture type, water, fertilizer, and spreading capabilities affect applications of zeolites, which makes it difficult to give specific application rates that work for all. Appropriate application rates should be determined using test plots before applying on a broad scale. For example, on a test plot of 100 ft^2, apply 2.5 to 5 lb to simulate a 3.5 to 4.0% application rate. For applications with compost and manure, adding about 5 to 20% of the total volume to the composting pile will increase nutrient availability in the compost and also reduce NH_3 and nitrous oxide (N_2O) greenhouse gas emissions (Wang et al. 2012).

Challenges to zeolite use for soil amendment

The major challenge with zeolite application in alkaline Arizona soils could be potential increases in soil pH. Some studies have reported increases soil pH although others reported a decrease, so check its effects on your soil pH in test plots before applying to a larger area. Applications to compost or manure are less likely to cause unacceptable soil pH changes. Removing zeolite from the soil after application is not practical, so it's very important to initially test for effectiveness in very small areas of land. Input cost could be another problem, especially for large-scale operations. However, a plan for yearly applications of small quantities could build up zeolites economically over time.

Conclusion

The use of zeolites in crop production may offer benefits relating to improving soil nutrient retention, soil water infiltration, reduced water run-off, increased soil WC, and crop yield potentials. Other benefits include reducing salt and heavy metals leaching from soil and greenhouse gas emissions. However, the use of zeolites in crop production has the potential for increasing soil pH from undesirable levels, and application of zeolites may increase production cost. More investigations on zeolite application in crops could lead to fertilization strategies that will reduce application costs and effects on soil pH.

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