Title: Establishment of Vegetation Using Zeolite (Clinoptilolite) in Regions of Shallow Groundwater in New Mexico

Key Words: water wicking, capillary movement of water, dryland restoration, vegetation in arid environments, zeolites, clinoptilolite, invasive plant species

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Abstract

Invasive plant species, such as saltcedar *(Tamarix* spp.), have replaced indigenous vegetation in many areas of the southwest U. S.. Many of these invasive species use more water than indigenous species, provide poor habitat for wildlife, increase fire frequency and intensity, or are otherwise considered as undesirable. However, many attempts to remove the undesired vegetation with replacement by beneficial species have failed due to the unavailability of water. This study describes a method to ameliorate the problem due to a lack of water by adding zeolites to the soil. Zeolites may act as a wicking material under certain conditions and draw water through capillary action from a shallow groundwater table up to the root zone of newly established plants allowing water to move to the plant's roots and thus reduce dependence on surface water or precipitation.

Introduction

Management of invasive plant species in the arid regions of the southwestern U.S. is a challenge. Federal, state and local government agencies have spent millions of dollars with exhaustive efforts to establish vegetation while managing invasive species. The intention was to provide a healthy and diverse ecosystem while reducing water lost through evapotranspiration by invasive plants such as saltcedar *(Tamarix* spp.). Reports comparing the excessive water use of saltcedar to native species vary widely depending on investigative methods used (e.g. Nagler et al. 2003, Bawazir 2000, Devitt et al. 1998, van Hylckama 1974), climate (Cleverly et al. 2002, Bawazir 2000) and the water use requirements of replacement vegetation. However, in most cases it is generally thought that a canopy of saltcedar will consume more water than grass and/or shrub communities.

In many cases where groundwater is relatively shallow (within 10 feet of the soil surface), traditional revegetation methodologies relying on available precipitation in the arid Southwest have had little or no success with the exception of pole plantings. Pole planting species such as cottonwood (*Populus* spp.) and willows (*Salix* spp.) have often been employed within these sites at considerable expense (Taylor et al. 1999, Taylor and McDaniel 1998). The long term sustainability of these plantings is questionable given the limited opportunity for recruitment of new trees and elevated soil salinity levels due to the absence of over-bank flooding, and other anthropogenic activities. Strategies to establish grasses and shrubs on these sites may be more appropriate and certainly more apt to reduce depletions of water within the system.

Conventional revegetation management practice is to clear invasive species and allow desirable vegetation to establish naturally, or in certain cases re-seed and/or transplant potted plants that are initially grown in greenhouses. While these methodologies seem very practical, it may not be possible or cost-efficient to provide the moisture that young plants and/or seeds require during early development to establish a sustainable population. The approach to revegetation described here uses a zeolite known as clinoptilolite to raise shallow groundwater by capillary action to or near the soil surface for use by plants. This method is referred herein as the water wick method. In some aspects this methodology is similar to underground drip irrigation where sufficient moisture is provided to plants or seeds for establishment. The advantage of this methodology is that plants and/or seeds will have sufficient moisture to increase their survivability and sustain growth during periods of drought. This method increases the probability of successful establishment of herbaceous and shrubby plant materials under dryland conditions. It was hypothesized that these transplants would have enough soil moisture to support growth and their root systems would reach the capillary fringe of a shallow water table to sustain their long-term establishment. The water wick method would be limited to areas of relatively shallow groundwater. The water wick method combined with tall pot planting technology (the use of plant materials with long roots or stems capable of deep burial) , such as that used by the Los Lunas Plant Materials Center, Natural Resources Conservation Service may further extend the range of use of this methodology.

Background

Saltcedar is one of the major invasive species commonly found in New Mexico and other riparian regions of the desert southwest where the groundwater table is shallow. It is well known and documented in the literature (Everitt et al. 2006, Duncan and Clark 2005, Kerpez and Smith, 1989, Horton and Campbell 1974) that invasive species such as saltcedar in riparian regions have negative environmental, economical and societal impacts. Many federal, state, and local government agencies, as well as private individuals, have undertaken efforts to reclaim areas infested with saltcedar with limited success in establishing desirable vegetation. Failure can often be attributed to factors such as lack of soil moisture during plant establishment, elevated soil salinity, diseases, and competition by more aggressive plants. Among these factors, lack of water is the most significant limitation to successful establishment of beneficial vegetation. Water must be available at the critical time of the season in order to be successful. Prolonged drought coupled with artificial operation of the rivers has hindered revegetation while allowing exotic plants such as saltcedar to encroach into these riparian regions.

Many attempts to restore vegetation in post-treated areas of saltcedar have been unsuccessful due mainly to the unavailability of water when it is needed. An example of an unsuccessful attempt using a practical methodology was experienced by Adkins and

Tanzy (personal data). They attempted to establish native vegetation by seeding and transplanting deep rooted grasses and shrubs to post-treated saltcedar sites in New Mexico during summer months when monsoon rains were likely to occur. Seeding was conducted utilizing a no-till drill and transplanting was done in the following manner. The site was cleared of annual weeds and the soil surface was windrowed to maximize concentration of available precipitation into depressions or ditches (figure 1). Transplants of giant sacaton (*Sporobolus wrightii*) were placed in the bottom of the ditches and received one initial watering (figure 2).

Figure 1. Cleared site with artificial depressions for transplants.

Figure 2. Transplanted giant sacaton in artificial depressions.

It was hypothesized that given normal monsoon rainfall these plantings would have enough soil moisture to support growth and that their root systems would reach the capillary fringe of a shallow water table to sustain their long-term establishment. Once established, giant sacaton provides both a windbreak and a seed source for further recruitment of desirable vegetation. This methodology involves limited plantings configured to affect the microclimate within the sites, creating more favorable conditions for maintaining soil moisture and mitigating the effects from wind and sun scald. Similar plantings have been successful given timely precipitation.

However, the recent extended drought, insufficient monsoon rains, hydrologic alteration and operation of the river systems in the region contributed to the failure of this attempt and many more like it. In the absence of irrigation, establishment of desirable vegetation is precarious at best. Adkins and Tanzy, from many years of field experience and observations on the significance of moisture, surmised that success might be possible by bringing water from the shallow water table up to the root zone rather than relying on the plants' ability to reach the water table without adequate precipitation. This is the basis of the methodology proposed here.

Desert riparian sites in New Mexico generally receive rainfall in the amount of 8 to 10 inches annually and at least 60% of the precipitation comes during monsoon summer months. The rain events which occur during summer months are mostly of high intensity and short duration and are scattered. In some cases the high intensity and short duration storms may negatively impact sites through erosion and deposition.

The methodology proposed here is to use a zeolite (clinoptilolite) to raise shallow groundwater by capillary action (wicking) to or near the soil surface (figure 3). This would be achieved by backfilling auger holes and/or trenches which extend to the water table with clinoptilolite. Plantings and/or seedlings would be placed in or in close proximity to the backfilled material.

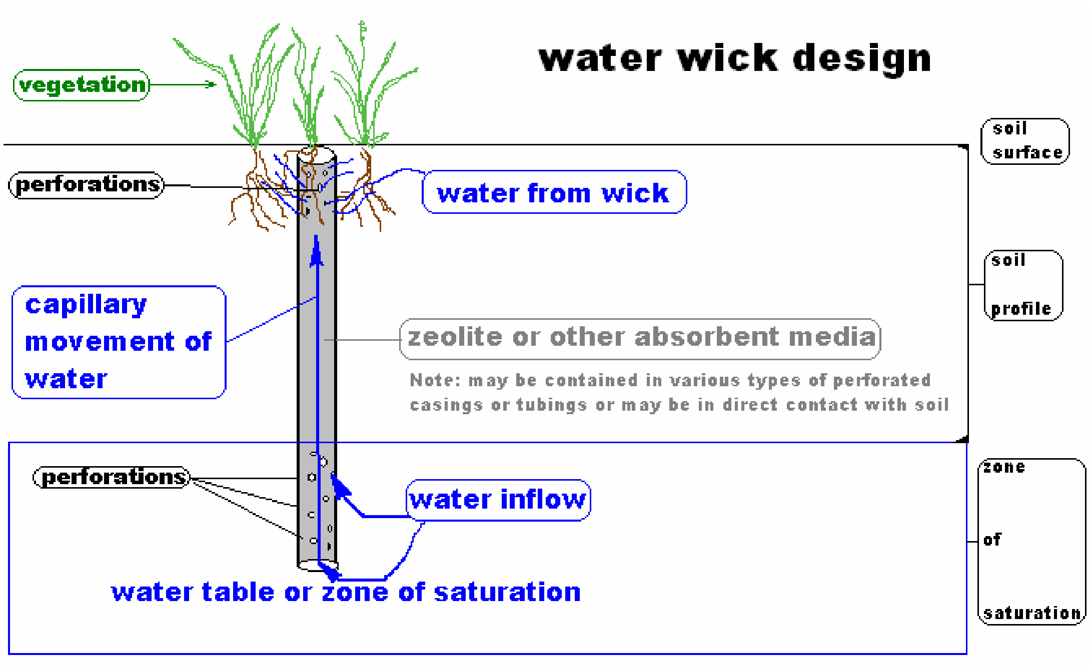

Figure 3. A schematic of the water wick method using clinoptilolite.

The water wick method would provide initial moisture for seedling/transplant establishment and sustain plant growth during periods of no rain and when the shallow groundwater drops to levels of 8 to 10 ft. The practicality of this method is based upon the inexpensive nature of zeolites in addition to limiting the number of installations necessary to pioneer the site with a few plants for seed source and recruitment.

Zeolite Properties

Zeolites are a volcanogenic sedimentary mineral composed primarily of aluminosilicates. The mineral has a three-dimensional crystal lattice, with loosely bound cations, capable of hydrating and dehydrating without altering the crystal structure (Holmes, 1994). This provides a natural material with the ability to exchange ions, absorb gases and vapors, act as molecular-scale sieves (Breck, 1974), and catalyze reactions owing to fixed pore sizes and active sites in the crystal lattice (figure 4).

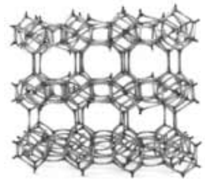

Figure 4. Zeolite structure (Source: International Zeolite Association).

Zeolites have increasingly been used in many industrial, agricultural and environmental applications (Polat et al., 2004). About 40 natural zeolites and 100 synthetic zeolites exist. It was reported by Polat et al. (2004) that of the 40 naturally occurring zeolites studied by research groups, the most well known ones are clinoptilolite, erionite, chabazite, heulandite, mordenite, stilbite, and philipsite. Among these types clinoptilolite is most commonly used in agricultural practices as a soil amendment and for promoting nitrogen retention in soils (Polat et al., 2004; Wehtje et al., 2003; He et al., 2002; Nus, 1991; MacKown and Tucker, 1985). It is a natural, inert, non-toxic substance that is federally classified as "generally regarded as safe (GRAS)" in most applications and is exempt from most regulations and reporting when used in accordance with good agricultural practices.

A commercial source of clinoptilolite is mined by the St. Cloud Mining Company in the south central area of New Mexico, about 4 miles south of Winston, Sierra County, NM (Bowie et al., 1987). The deposit is located at the southern end of the Winston graben in a metamorphosed volcanic ash about 29 million years old (McIntosh et al., 1991) which has been altered by the action of alkaline groundwater.

Some physical and chemical specifications of the clinoptilolite are presented in Table 1. The mineral content by weight is 75 to 85% clinoptilolite with varying amounts of quartz, feldspar, and virtually no clay or fibrous minerals. The clinoptilolite has been used as a soil amendment in hundreds of golf courses and sporting fields throughout the Western Hemisphere, and has also been used for hydroponic experiments of the USA Space Shuttle Program. It's ability to repeatedly hydrate and dehydrate, to adsorb nitrogen in the form of ammonium and then release it upon demand by a plant root system, has made it a valuable tool in agricultural, horticultural and turf applications.

Table 1. Physical and chemical properties of St. Cloud Clinoptilolite.

Bulk Density (Aggregate, dried. Common sizes)	44-52 lbs/ft^3
Clinoptilolite Content	75 to 85%
Cation Exchange Capacity (CEC)	0.8 – 1.2 meq/g
Surface Charge Density	10.1E-23 meq/Å^2
Molecular Ratio	5.1 (Si/Al)
Pore Size (diameter)	4 - 7 Å
Pore Volume	≤ 52%
External Surface Area	14 to 15 m^2/g
Total Surface Area	≤ 800 m^2/g

Swelling Index ....nil

• Chemical composition for selected elements by x-ray fluorescence (in weight % or ppm, as noted):

Ca 2.4 %	Mg 0.8 %	Na 0.1 %	Fe 0.5%	Cu < 10 ppm
K 1.1 %	P <0.01%	Al 2.9 %	Si 31.9%	Zn 48 ppm

• Major exchangeable cations
Rb, Li, K, Cs, NH_4, Na, Ca, Ag, Cd, Pb, Zn, Ba, Sr, Cu, Hg, Mg, Fe, Co, Al, Cr. (Selectivity of above cations is a function of hydrated molecular size and relative concentrations.)

• Primary adsorbing gases:
CO, CO_2, SO_2, H_2S, NH_3, HCHO, Ar, O_2, N_2, H_2O, He, H_2, Kr, Xe, CH_2OH, freon, formaldehyde, and mercaptans

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Clinoptilolite has been recognized as a material that can improve sustainability of the practices described above, and conserve valuable resources such as water, while protecting groundwater quality by significantly reducing leaching of nutrients. Based on preliminary investigations described below, clinoptilolite is considered as a natural material appropriate for the water wick method.

The particle sizes of clinoptilolite materials being considered for utilization in the water wick method include 6 x 14 mesh (3.4 x 1.4 mm), 14 x 40 mesh (1.4 x 0.42 mm) and – 40 mesh (<0.42mm).

Methodology

In New Mexico, efforts to treat and/or remove saltcedar are in progress. The potential for establishment of desirable plants will be increased by using the water wick method as it will provide a pathway to supply adequate moisture for plant establishment and growth.

Preliminary work by Tanzy and Adkins (personal data) showed that water rose to a height of 5 ft by capillary action from a water surface in 28 days using a 2-in polyvinyl chloride (PVC) pipe filled with fine grain size (40 mesh) clinoptilolite. Another investigation by Bawazir and Lopez (personal data) tested at New Mexico State University Hydraulics Laboratory showed that water rose to a height of 6 ft by capillary action in about 40 days inside a 4-inch acrylic pipe filled with the 40-mesh clinoptilolite. The filled tube was placed on top of sandy loam soil saturated with water in a 50 gallon barrel. The soil was obtained near the Rio Grande to mimic shallow aquifer characteristics of riparian regions of the Middle and Lower Rio Grande. A similar test using split core of fine clinoptilolite and sandy loam soil is shown in figure 5. This test showed that there is minimum lateral movement of water from clinoptilolite to the adjacent coarser sandy loam soil. This test answered two major concerns: i) is there lateral movement that could hinder the wicking of water by clinoptilolite to a possible maximum height and ii) could zeolite be used directly in the field without the use of a casing for simplicity and cost reduction.

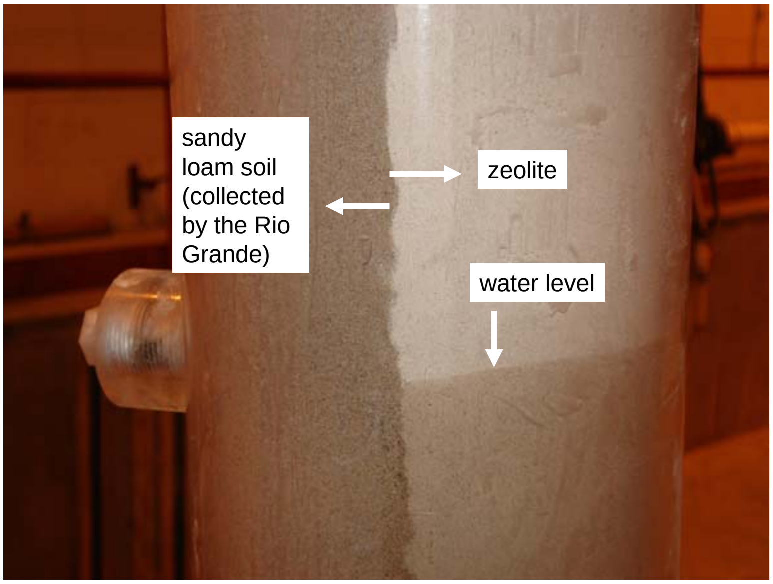

Figure 5. Split test of fine clinoptilolite and sandy loam soil in 4-in acrylic pipe.

Further investigations of the capillary rise of water using different mixtures of clinoptilolite and in contact with various soil textures are in progress. Preliminary results from these studies indicate that the clinoptilolite water wick method is feasible under field conditions.

Proposed Work

The water wick method using clinoptilolite to establish desirable vegetation in regions of shallow groundwater in New Mexico is new and has never been previously tested. The hypothesis is that clinoptilolite will allow water to rise by capillary action from shallow groundwater up into the root zone. This procedure would support the establishment and assist in sustaining beneficial vegetation in arid areas where the groundwater table is shallow but not easily accessible to plants, and where rainfall is infrequent.

Field experiments are needed to further demonstrate the efficiency of the wicking method. The methodology proposed here is to drill various diameter holes and/or excavate trenches (this will be decided based on location and field conditions) to shallow groundwater water in post-treated areas and fill them with clinoptilolite during the winter (dormant) season. This will allow enough time for water to rise by capillary action in clinoptilolite filled holes and or trenches from the groundwater table. Desirable plants will be seeded or transplanted near or directly in the clinoptilolite.

The proposed work is as follows:

1. Determine clinoptilolite hydraulic properties in the laboratory. This will include soil moisture characteristic curves for different particle size classes of clinoptilolite that are commercially available. A soil moisture characteristic curve shows the relationship between soil moisture content and soil moisture tension. This will allow the determination of the amount of water available to plants, commonly determined for agricultural crops as water retained between -1/3 bar and -15 bars (-333 cm and -15,000 cm). This information is useful in predicting water and contaminant transport in soils.

2. Measure capillary rise of water and moisture content in tubes filled with different mixtures of clinoptilolite in the laboratory.

3. Grow beneficial plants in controlled environments such as in a greenhouse to determine the extension of root development and their vigor using different mixtures of clinoptilolite.

4. Grow plants in the natural field environment using clinoptilolite and compare to those without clinoptilolite. This will demonstrate the validity of the water wick method using the clinoptilolite.

5. Monitor the rise of water (capillary rise) under field conditions to assure that water reaches the root zone.

Dissemination of Information

A technical completion report will be submitted to the sponsoring agencies. Information will be disseminated through research conference presentations, peer reviewed journal publication, public field tours, and publication on the internet.

Time Schedule

The proposed work is anticipated for at least 3 years.

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