World Journal of Advanced Research and Reviews

eISSN: 2581-9615 CODEN (USA): WJARAI

Cross Ref DOI: 10.30574/wjarr

Journal homepage: https://wjarr.com/

(RESEARCH ARTICLE)

Check for updates

Study and evaluation of natural zeolite and dried zeolite for the cultivation of friggitello pepper

Domenico Prisa *

CREA Research Centre for Vegetable and Ornamental Crops, Council for Agricultural Research and Economics, Via dei Fiori 8, 51012 Pescia, PT, Italy.

World Journal of Advanced Research and Reviews, 2023, 19(02), 632–641

Publication history: Received on 01 July 2023; revised on 10 August 2023; accepted on 12 August 2023

Article DOI: https://doi.org/10.30574/wjarr.2023.19.2.1626

Abstract

Research objective: The aim of this research was to evaluate whether differences exist between natural and dried chabazite zeolite in the cultivation of Friggitello peppers

Materials and Methods: The experiments, which started in January 2023, were conducted in the CREA-OF greenhouses in Pescia (Pt), Tuscany, Italy (43°54′N 10°41′E) on 'Friggitello' pepper seedlings. The plants were placed in pots with a diameter of 16, 10 plants per 3 replications, for a total of 30 seedlings per experimental thesis. The pepper trial included the following theses (irrigated and fertilised): i) peat 70% + pumice 30%; ii) peat 70% + pumice 10% + natural chabazite zeolite 20%; iii) peat 70% + pumice 10% + dried chabazite zeolite 20%. Plant height, number of leaves, vegetative weight, root volume and length, number of fruits (peppers), fruit weight and the number of microorganisms in the substrate were determined on 18 July 2023.

Results and Discussion: The experiment showed that the use of chabazite zeolite can indeed significantly improve the vegetative and root growth and productive and size fruits of Friggitello pepper plants (Table 1). Clear differences in growth are evident between the use of natural zeolite (ZEONAT) and dried zeolite (ZEOESS), with the natural zeolite performing better with regard to all agronomic parameters analysed. In the substrate analysis, a greater presence of microbial biomass was found in the zeolite theses than in the control theses, with greater superiority of microorganisms in the substrate with natural chabsite zeolite. Zeolites are used successfully in the cultivation of many crops. Including cereals, vegetables, grapes and other fruits. By enhancing the absorption ability of soil, zeolite enhance the long-term quality of soil by retaining nutrients.

Conclusions: Due to its high absorption rate, cation exchange, catalysis, and dehydration capacity, chabazite is the most common zeolite for agricultural applications. Therefore, zeolite fertilizers are used to improve plant growth by improving their value. Additionally, they can be used as molecular sieves or filters and retain nitrogen in the manure and sludge they produce. For agricultural production, zeolites must have uniform properties and have unique properties such as cation exchange capacity, pH, and B content. Important differences exist between the use of a natural zeolite and a dried one, especially in the significant presence of useful microbiology in the interactions with the plant, in terms of growth and protection.

Keywords: Alternative substrates; Zeolites; Plant growth; Pepper; Rhizosphere

* Corresponding author: Domenico Prisa

1. Introduction

Zeolite has been introduced as a scientifically correct definition of diagenised pyroclastic rocks with a predominant (> 50%) zeolite content (i.e., quartz, cristobalite, feldspar, plagioclase) and subordinate quantities of other silicate phases (quartz, cristobalite, feldspar, plagioclase) in place of generic terms used in the literature ("natural zeolite", "sedimentary zeolites", "zeolite-rich rocks", "zeolite-rich tuffs", etc. [1,2]. The most common zeolitic species in "zeolites" are clinoptilolite present in variable quantities (40-60%) in diagenised "acid" tuffs widespread in many European (Slovenia, Czechoslovakia, Hungary, Romania, Bulgaria, Greece) and non-European (Turkey, Iran, Russia, United States, Cuba, Japan, China, Australia) countries [3,4]; chabazite and phillipsite present in variable amounts (30-70%) in Italian "basic" ignimbrites ignimbrites with alkaline-potassium ignimbrites [5]. Zeolite content characterizes zeolites in several ways: 1) high cation exchange capacity (140-210 meq/100 g), 2) reversible dehydration, and 3) structural cryptoporosity [6,7]. As a result of their lithological nature (micro and macroporosity in texture, lithoid consistency), they are also characterized by water retention, mechanical resistance, permeability, and low density [8,9]. According to zeolite type and concentration (weight percentage), zeolite has different properties [10]. A volcanic rock's other properties are determined by its nature (tuff, suffice, ignimbrite) as well as its diagenetic process (water system 'open', 'closed', 'autoclave'). As chabazite and phillipsite are zeolitic species with a cation exchange capacity (CSC) of 330-340 meq/100g and occur in micro-and macroporous ignimbrites, clinoptilolite is a zeolitic species with a cation exchange capacity (CSC) of 220-230 meq/100g and occurs in compact tuffs, the chabazite and phillipsite zeolites widespread in Italy show higher cation exchange capacity (CSC) and water retention values and lower density values than the clinoptilolite zeolites widespread abroad [11–13]. For a qualitative plant growth result, it is crucial to use a large amount of zeolite per square meter, both within the root zone and on the surface of the soil. Zeolite is normally added to the substrate mixture at a rate of 2 kg per square metre in field situations, while in pot cultivation at a rate of 20% by weight [14–17]. The abilities of zeolite in terms of cation exchange and water retention are very important in sandy soils and in all the situations where a lack of water resources is observed. Experiments have shown that the quality of zeolite and the quantities used in various crops can alter plant growth and plant resistance to biotic and abiotic stresses [18–20].

2. Aspects of zeolites in agriculture and the environment

Thousands of lab and field experiments have revealed that zeolites, particularly Italian zeolites containing chabazite, have high drainage capacity, water retention, and excellent extraction capacity, as well as high potassium (K) and low sodium (Na) contents [21,22]. The use of fertilizers and irrigation water can be reduced, and agronomic production can be increased as a result [23,24]. In addition to reducing water usage for irrigation, zeolite's permeability and high water retention minimize, respectively, the loss of irrigation and meteoric water through surface runoff in soils with a high clay component (impermeable) and rapid drainage in soils with a high sandy component (low water retention) [25,26]. The infinitely reversible property of the zeolitic water allows it to maintain almost constant levels of humidity and temperature at the root level due to its infinitely reversible property of dehydration (endothermic process) and rehydration (exothermic process) [27]. A number of experiments were conducted to reduce the adverse effects of high temperatures and droughts [28]. Zeolite is shown to provide more excellent protection for ornamental plants, as well as other species, such as vines, against cold when used in substrate or soil. When temperatures are suitable for cultivation, leaf scorch is observed to restart more rapidly [29,30]; also, excessive levels of salinity of irrigation water are observed to decrease [31]. According to several research studies, adding 20% zeolite to the growing medium has been shown to improve plant growth and leaf quality in *Loropetalum sinensis* . Prisa [32] has shown that the use of zeolite in the growing medium can reduce (or eliminate in some cases) the stress effects on plants caused by excess salts in irrigation water. Using less fertilizer increases soil cation exchange capacity (CSC), which is an integral part of the soil [33]. Ammoniacal nitrogen (NH_3) that is not needed by crops is temporarily removed through leaching into the groundwater as nitrates and volatilization into the atmosphere as greenhouse gases. Aside from reducing phosphorus retrogradation (from monocalcium phosphates supplied by fertilizers), this reduces crop assimilation of tricalcium phosphate ($Ca_3(PO_4)_2$) by reacting with calcium (Ca) in the soil, which is an insoluble phosphate and so cannot be assimilated by crops) [34–36]. Zeolite releases nitrogen slowly and gradually according to the phenological needs of crops [37–39]. Due to its reflective properties, zeolite also makes it difficult for pathogenic insects to locate ripe fruits and absorbs ethylene produced by ripe fruits, which carries them to plant structures. In new experiments, zeolites have been shown to attract beneficial microbial colonies, which can enter into symbiosis with plants and enhance their water and nutrient uptake and defence by producing secondary metabolites [40–42].

2.1. Research Objectives

The aim of this research was to evaluate whether differences exist between natural and dried chabazite zeolite in the cultivation of Friggitello peppers (Figure 1).

Figure 1 Details of the substrates and plants used in the experiment at CREA-OF

3. Material and methods

The experiments, which started in January 2023, were conducted in the CREA-OF greenhouses in Pescia (Pt), Tuscany, Italy (43°54′N 10°41′E) on 'Friggitello' pepper seedlings.

The plants were placed in pots with a diameter of 16, 10 plants per 3 replications, for a total of 30 seedlings per experimental thesis.

All plants were fertilised with a controlled-release fertiliser (2 kg m-3 Osmocote Pro®, 9-12 months with 190 g/kg N, 39 g/kg P, 83 g/kg K) mixed with the growing medium before transplanting. The pepper trial included the following theses (irrigated and fertilised)

- peat 70% + pumice 30% (CTRL)
- peat 70% + pumice 10% + natural chabazite zeolite 20% (ZEONAT)
- peat 70% + pumice 10% + dried chabazite zeolite 20% (ZEOESS)

The plants were watered once a day and grew for seven months. The plants were drip-irrigated. Irrigation was activated by a timer whose programme was adjusted weekly according to the weather conditions and the leaching fraction.

Plant height, number of leaves, vegetative weight, root volume and length, number of fruits (peppers), fruit weight and the number of microorganisms in the substrate were determined on 18 July 2023.

3.1. Methods of analysis

Microbial count: direct determination of the total microbial count by microscopy of the cells contained in a known volume of sample using counting chambers (Thoma chamber). The surface of the slide is etched with a grid of squares, with the area of each square known. Determination of viable microbial load after serial decimal dilutions, spatula seeding (1 ml) and plate counting after incubation [32];

3.2. Statistics

The experiment was conducted in a randomised complete block design. Collected data were analysed by one-way ANOVA, using the univariate GLM procedure, to assess significant differences ($P \leq 0.05$, 0.01 and 0.001) between treatments. Mean values were then separated using the LSD test at multiple intervals ($P = 0.05$). Statistics and graphs were supported by the programmes Costat (version 6.451) and Excel (Office 2010).

4. Results

The experiment showed that the use of chabazite zeolite can indeed significantly improve the vegetative and root growth of Friggitello pepper plants (Table 1). Clear differences in growth are evident between the use of natural zeolite (ZEONAT) and dried zeolite (ZEOESS), with the natural zeolite performing better with regard to all agronomic parameters analysed. In particular for plant height (Figure 2), number of leaves, vegetative and root weight (Figure 3), and root length. In the substrate analysis, a greater presence of microbial biomass was found in the zeolite theses than in the control theses, with greater superiority of microorganisms in the substrate with natural chabsite zeolite.

Table 1 Evaluation of the use of different zeolites on Friggitello pepper

Groups	Plant height (cm)	Leaves number (n°)	Substrate total bacteria (Log CFU/g soil)	Vegetative weight (g)	Roots volume (cm³)	Roots length (cm)	Fruits number (n°)	Fruits weight (g)
CTRL	44.78 c	24.83 c	1.28 c	59.27 c	36.04 c	6.28 c	11.26 c	36.06 c
ZEONAT	50.78 a	35.81 a	2.90 a	66.82 a	40.58 a	9.76 a	15.21 a	42.57 a
ZEOESS	47.80 b	28.86 b	1.61 b	62.33 b	38.79 b	7.65 b	12.83 b	38.39 b
ANOVA	***	***	***	***	***	***	***	***

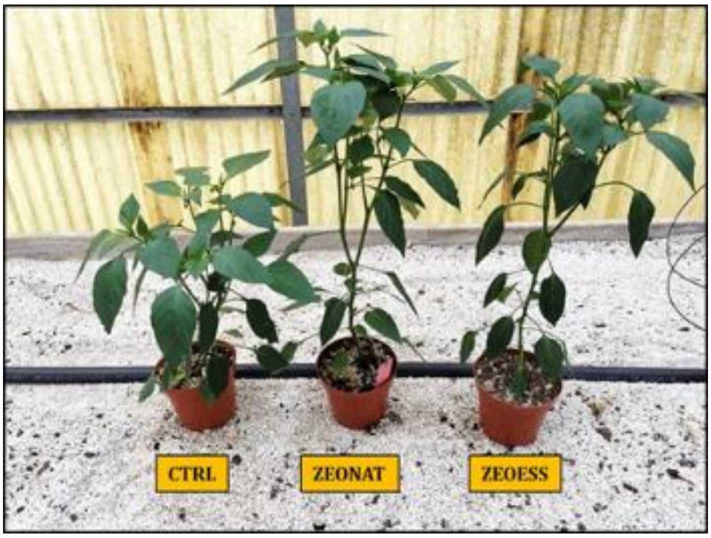

Figure 2 Comparison between the thesis with peat 65% + pumice 30% + (CTRL), peat 70% + pumice 10% + natural chabazite zeolitite 20% (ZEONAT), peat 70% + pumice 10% + dried chabazite zeolite 20%(ZEOESS) on the vegetative growth of Friggitello pepper

Figure 3 Comparison between the thesis with peat 65% + pumice 30% + (CTRL), peat 70% + pumice 10% + natural chabazite zeolite 20% (ZEONAT), peat 70% + pumice 10% + dried chabazite zeolite 20%(ZEOESS) on the roots growth of Friggitello pepper

The production indices also show an increase in production in the theses with zeolite, with an increase in production in the thesis with natural zeolite (ZEONAT) with 15.21 fruits, compared to dried zeolite (ZEOESS) with 12.83 and control with 11.26. Differences were also found in the fruit weight with natural zeolite where the weight was 42.57 g, compared to dried zeolite with 38.39 g and control with 36.06 (Figure 4).

One-way ANOVA; n.s. – non significant; *,**,*** – significant at P ≤ 0.05, 0.01 and 0.001, respectively; different letters for the same element indicate significant differences according to Tukey's (HSD) multiple-range test (P = 0.05).Legend: (CTRL) peat 70% + pumice 30%; (ZEONAT) peat 70% + pumice 10% + natural chabazite zeolitite 20%; (ZEOESS) peat 70% + pumice 10% + dried chabazite zeolite 20%

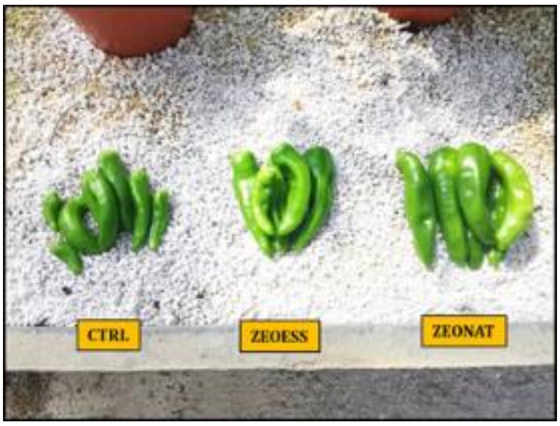

Figure 4 Comparison between the thesis with peat 65% + pumice 30% + (CTRL), peat 70% + pumice 10% + natural chabazite zeolite 20% (ZEONAT), peat 70% + pumice 10% + dried chabazite zeolite 20%(ZEOESS) on the fruits size of Friggitello pepper

5. Discussion

The discovery of zeolite as a mineral dates back to 1756, when a Swedish mineralogist, Fredrich Cronstet, began collecting crystals from a copper mine in Sweden. Words meaning "boiling stones", since they can froth at temperatures up to 200°C [43]. For two hundred years following their discovery, zeolites were considered minerals found in volcanic rocks. Since the 1950s, they have been rediscovered, and their commercial production and use have begun in the world [44–46]. To date, more than forty types of zeolites have been reported by different groups. Among these minerals, analcime (sometimes known as analcite), clinoptilolite, erionit, chabazite, mordenite, and philipsite are well known [47]. Also, more than 150 zeolites have been synthesized. Due to their unique adsorption, ion exchange, molecular sieve, and catalytic properties, these naturally occurring and synthetic minerals are widely used in commercial applications [48]. In order to ensure that the source of zeolites can provide sufficient quantities with uniform characteristics as well as unique properties (cation exchange capacity, pH, and B content) for application and commercial processing, extensive research is necessary. Zeolites are being researched to enhance their use [49,50]. Many minerals have cage-like structures, have similar properties, or are associated with zeolites, but they are not actually them. Therefore, zeolites without well defined chemical characteristics may cause severe problems in their application [51,52].

Table 2 Characteristics of some naturally occurring zeolites (Doğan, 2003)

Zeolite	Porosity (%)	Heat stability	Ion Exchange Capacity (meq/g)	Specific gravity (g/cm^3)	Bulk Density (g/cm^3)
Analcime	18	High	4.54	2.30	1.85
Chabazite	47	High	3.84	2.10	1.45
Clinoptilolite	34	High	2.16	2.25	1.15
Erionite	35	High	3.12	2.08	1.51
Heulandite	39	Low	2.91	2.20	1.69
Mordenite	28	High	4.29	2.15	1.70
Philipsite	31	moderate	3.31	2.20	1.58

Besides agriculture, zeolites have many applications including ion exchange, filtering, odour removal, chemical sieve, water softener, and gas absorption. Among these are production, soil stabilization, building materials, anticorrosive paint components, defluorination of industrial wastes, desulphurization of flue gas, methylene blue and mercury removal, copper recovery from phosphate fixation, chlorine phenol removal, neutralization of acid wastes, sewer cleanup, and the removal of heavy metals and ammonium ions [53–55] (Table 2).

Zeolites are composed of pores and cornersharing aluminosilicate (AlO_4 and SiO_4) tetrahedrons, joined into 3dimensional frameworks. The pore structure is characterized by cages approximately 12Å in diameter, which are interlinked through channels about 8Å in diameter, composed of rings of 12 linked tetrahedrons [56–58]. The pores are interconnected and form long wide channels of varying sizes depending on the mineral. With these channels, resident ions and molecules can move easily in and out of the structure, forming honeycombs or cages. Aluminium results in a negative charge, which is balanced by positively charged cations [59]. Zeolites have large vacant spaces or cages within, resembling honeycombs or cages. The use of zeolite in agriculture helps improve the efficiency of applied fertilizers, thus promoting a better crop yield [60]. Some authors for example, reported that 48 pounds/acre of zeolite can enhance yield. With 2 to 8 kg/tree, this mineral contributes to a better new orchard establishment. Zeolites are used successfully in the cultivation of many crops. Including cereals, vegetables, grapes and other fruits [61,62]. By enhancing the absorption ability of soil, zeolites enhance the long-term quality of soil by retaining nutrients. In addition to nitrogen (N) and potassium (K), it also includes calcium, magnesium, and microelements, which are important plant nutrients. Thus, using zeolite can reduce the amount of N and K fertilizer needed to achieve the same yield, prolong their activity, or boost their efficiency. In sandy soils, where high levels of nutrients cannot be retained, large losses of fertilizers occur due to leaching [63,64].

In this way, zeolites will enhance the growth and development of plants by reducing the loss of nutrients [65]. A crystalline structure in zeolite can hold water up to 60% of its weight, but water molecules in the pores are easily evaporated or reabsorbed without damaging the structure [66]. In addition to providing permanent moisture during dry times, zeolites also aid in rapid rewetting during irrigation and improve the lateral spread of water. Zeolites are capable of absorbing pesticides and reducing the amount of water needed for irrigation.

As well as positive cations such as sodium, potassium, barium, and calcium, negative-charged zeolites can trap positively charged groups such as water and ammonia. Because the negative charge within zeolites attracts both carbonate and nitrate ions, alkali and soil alkali metallic cations are attracted in the same way, and water can be absorbed by zeolites [67]. Zeolites are good ion exchangers since they are relatively mobile due to their weak attraction, which allows them to replace absorbed cations [68]. In contrast to other soil amendments (such as lime), zeolite remains in the soil permanently to improve nutrient retention. By retaining beneficial nutrients in the root zone, its addition to soil will significantly reduce water and fertilizer costs. In addition to keeping the soil aerated and moist, natural zeolite also keeps it active for a long time because of its porous structure [69,70]. By using zeolite with fertilizers, soil pH levels will be buffered, reducing the need for lime application. Due to its marginal acidity, zeolite is not acidic but marginally alkaline [71,72]. The irrigation and maintenance costs associated with golf courses and sport fields can be very high when this mineral is used. In this trial, the use of chabazite zeolite significantly improved the vegetative and root growth of Friggitello peppers, with effects also evident on the microbial biomass of the added substrate. There was also an increase in production in the treated theses both in terms of quantity and fruit size. The trial highlighted the significant differences that exist between the use of a dried zeolite and a natural one, highlighting the better performance in agronomic and productive terms, of the second one.

6. Conclusion

Due to its high absorption rate, cation exchange, catalysis, and dehydration capacity, chabazite is the most common zeolite for agricultural applications. Therefore, zeolite fertilizers are used to improve plant growth by improving their value. Additionally, they can be used as molecular sieves or filters and retain nitrogen in the manure and sludge they produce. For agricultural production, zeolites must have uniform properties and have unique properties such as cation exchange capacity, pH, and B content. Important differences exist between the use of a natural zeolite and a dried one, especially in the significant presence of useful microbiology in the interactions with the plant, in terms of growth and protection. A natural zeolite retains its characteristics intact and can better interact with the plant's root systems by increasing water and nutrient exchange.

Compliance with ethical standards

Acknowledgments

The research is part of the project ZEOAGRI: STUDY AND EVALUATION OF ZEOLITE AND DRIED ZEOLITE FOR THE CULTIVATION OF HORTICULTURAL CROPS. We would like to thank the company CAVE PIANDIRENA S.R.L for their cooperation and for providing the products for the research.

Disclosure of conflict of interest

The author declares no conflict of interest.

Statement of ethical approval

The present research work does not contain any studies performed on animal/humans subjects.

References

[1] Aainaa HN, Haruna Ahmed O, Ab Majid NM, Reinhart KO. Effects of clinoptilolite zeolite on phosphorus dynamics and yield of Zea mays L. cultivated on an acid soil. PLoS ONE. 2018; 13: e0204401.

[2] Al-Busaidi A, Yamamoto T, Inoue M, Eneji AE, Mori Y, Irshad M. Effects of zeolite on soil nutrients and growth of barley following irrigation with saline water. J. Plant Nutr. 2008; 31: 1159–1173.

[3] Kotoulas A, Agathou D, Triantaphyllidou I, Tatoulis T, Akratos C, Tekerlekopoulou A, Vayenas D. Zeolite as a potential medium for ammonium recovery and second cheese whey treatment. Water (Switzerland). 2019; 11: 136.

[4] Alimi T, Ajewole OC, Olubode-Awosola OO, Idowu EO. Organic and inorganic fertilizer for vegetable production under tropical conditions. J Agric Rural Dev. 2007; 1: 120–136.

[5] Allen ER, Ming DW. Recent progress in the use of natural zeolites in agronomy and horticulture. In Natural Zeolites (1993). Eds DW Ming and FA Mumpton. 1995; 477–490.

[6] Andronikashvili TG, Kadava MA, Gamisonia MK. Effect of natural zeolites on microbe landscape of some soils in Georgia. Abstracts, Sofia International Zeolite Meeting. 1995; 111–112.

[7] Andrzejewska A, Diatta J, Spizewski T, Krzesinski W, Smurzynska A. Application of zeolite and bentonite for stabilizing lead in a contaminated soil. Inzynieria ˙ Ekol. 2017; 18: 1–6.

[8] Hermassi M, Valderrama C, Font O, Moreno N, Querol X, Batis NH, Cortina JL. Phosphate recovery from aqueous solution by K-zeolite synthesized from fly ash for subsequent valorisation as slow release fertilizer. Sci. Total Environ. 2020; 731: 139002.

[9] Martínez TLM, Ivanova S, Louis B, Odriozola JA. Synthesis and Identification Methods for Zeolites and MOFs. Zeolites Met. Fram. 2019; 25–52.

[10] Bandura L, Franus M, Panek F, Woszuk A, Franus W. Characterization of zeolites and their use as adsorbents of petroleum substances. Przem. Chem. 2015; 94: 323–327.

[11] Bandura L, Panek R, Madej J, Franus W. Synthesis of zeolite-carbon composites using high-carbon fly ash and their adsorption abilities towards petroleum substances. Fuel. 2021; 283: 119173.

[12] Wang B, Chu C, Wei H, Zhang L, Ahmad Z, Wu S, Xie B. Ameliorative effects of silicon fertilizer on soil bacterial community and pakchoi (*Brassica chinensis* L.) grown on soil contaminated with multiple heavy metals. Environ. Pollut. 2020; 267: 115411.

[13] Belviso C. Zeolite for potential toxic metal uptake from contaminated soil: A brief review. Processes. 2020; 8: 820.

[14] Cataldo EC, Salvi LS, Paoli FP, Fucile MF, Masciandaro GM, Manzi DM, Masini CMM, Mattii GBM. Application of zeolites in agriculture and other potential uses: A review. Agronomy. 2021; 11: 1–14.

[15] Baghbani-Arani A, Jami MG, Namdari A, Karami Borz-Abad R. Influence of irrigation regimes, zeolite, inorganic and organic manures on water use efficiency, soil fertility and yield of sunflower in a sandy soil. Commun. Soil Sci. Plant Anal., 2020; 51: 711–725.

[16] Czarna-Juszkiewicz D, Kunecki P, Panek R, Madej J, Wdowin M. Impact of fly ash fractionation on the zeolitization process. Materials (Basel). 2020; 13: 1–13.

[17] Eslami M, Khorassani R, Fotovat A, Halajnia A. NH4+-K+ co-loaded clinoptilolite as a binary fertilizer. Arch. Agron. Soil Sci. 2020; 66: 33–45.

[18] Bikkinina LH, Ezhkov VO, Faizrakhmanov RN, Gazizov RR, Ezhkova AM, Fayzrakhmanov D, Ziganshin B, Nezhmetdinova F, Shaydullin R. Effect of zeolites on soil modification and productivity. BIO Web Conf. 2020; 17: 00117.

[19] Cadar O, Dinca Z, Senila M, Torok AI, Todor F, Levei EA. Immobilization of potentially toxic elements in contaminated soils using thermally treated natural zeolite. Materials (Basel). 2021; 14: 3777.

[20] Czuma N, Baran P, Franus W, Zabierowski P, Zarębska K. Synthesis of zeolites from fly ash with the use of modified two-step hydrothermal method and preliminary SO_2 sorption tests. Adsorpt. Sci. Technol. 2019; 37: 61–76.

[21] Cie´sla J, Kedziora K, Gluszczyk J, Szerement J, Jozefaciuk G, Franus W, Franus M. Environmental-friendly modifications of zeolite to increase its sorption and anion exchange properties. Physicochemical studies of the modified materials. 2019; 10: 112–126.

[22] Collins F, Rozhkovskaya A, Outram JG, Millar GJ. A critical review of waste resources, synthesis, and applications for Zeolite LTA. Microporous Mesoporous. Mater. 2020; 291: 109667.

[23] Foley JA. Si può nutrire il mondo e proteggere il pianeta? Le Scienze. 2021; 512.

[24] De Smedt C, Someus E, Spanoghe P. Potential and actual uses of zeolites in crop protection. Pest Manag. Sci. 2015; 71: 1355–1367.

[25] De Smedt C, Steppe K, Spanoghe P. Beneficial effects of zeolites on plant photosynthesis. Adv. Mater. Sci. 2017; 2: 1–11.

[26] Eroglu N, Emekci M, Athanassiou CG. Applications of natural zeolites on agriculture and food production. J. Sci. Food Agric. 2017; 97: 3487–3499.

[27] Ippolito JA, Tarkalso DD, Lehrsch GA. Zeolite soil application method affects inorganic nitrogen, moisture, and corn growth. Soil Science. 2011; 176: 136–142.

[28] Ming DW, Mumpton FA. Zeolites in soils. - Miner. Soil Environ. 1989; 873–911.

[29] Prisa D. Italian chabazitic-zeolitite and Effective microorganisms for the qualitative improvement of olive trees. Soc. Tosc. Sci. Nat., Mem. 2018; 125: 13–17.

[30] Filcheva EG, Tsadilas CD. Influence of clinoptilolite and compost on soil properties. Commun. Soil Sci. Plant Anal. 2002; 33: 595–607.

[31] Passaglia E. Zeolititi in agricoltura. Mitigazione delle problematiche ambientali conseguenti pratiche agricole e alla gestione dei reflui zootecnici. Informatore agrario. 2019;125.

[32] Prisa D. Effective Microorganisms And Chabazitic-Zeolites For The Improvement Quality Of Echinopsis Hybrids. Asian Academic Research Journal of Multidisciplinary. 2019; 6(2): 23–34.

[33] Ramesh K, Reddy DD. Zeolites and Their Potential Uses in Agriculture. Elsevier. 2011; 219–241.

[34] Prisa D. Germination Of Vegetable And Grassland species With Micronized chabazitic-Zeolites And Endophytic Fungi. IOSR Journal of Agriculture and Veterinary Science. 2019; 12: 32–37.

[35] Georgiev D, Zagora S. Synthetic zeolites - structure, classification, current trends in zeolite synthesis: review. Proceedingas of the International Science conference. 2009; 1–6.

[36] Mahmoud AWM, Swaefy HM. Comparison between commercial and nano NPK in presence of nano zeolite on sage plant yield and its components under water stress. Agriculture. 2020; 66: 24–39.

[37] Prisa D, Burchi G, Antonetti M, Teani A. Use Of organic or inorganic substrates for reducing the use of peat and improving the quality of bulbs and inflorescences in Asiatic Lily. Acta Horticulturae. 2011; 900: 143–148.

[38] Manjaiah KM, Mukhopadhyay R, Paul R, Datta SC, Kumararaja P, Sarkar B. Clay minerals and zeolites for environmentally sustainable agriculture. In: Modified Clay and Zeolite Nanocomposite. Materials. 2019; 309–329.

[39] Yuvaraj M, Subramanian KS. Development of slow release Zn fertilizer using nano-zeolite as carrier. J. Plant Nutr. 2018; 41(3): 311–320.

[40] Ghadamnan E, Nabavi SR, Abbas M. Nano LTA zeolite in water softening process: synthesis, characterization, kinetic studies and process optimization by response surface methodology (RSM). Journal of Water Environment and Nanotechnology. 2019; 4: 119–128.

[41] Gholamhoseini M, Ghalavand A, Khodaei-Joghan A, Dolatabadian A, Zakikhani H, Farmanbar E. Zeolite-amended cattle manure effects on sunflower yield, seed quality, water use efficiency and nutrient leaching. - Soil Tillage Res. 2013; 126: 193–202.

[42] Hall A. Zeolitisation of volcaniclastic sediments: The role of temperature & pH. - J. Sed. Res. 1998; 68: 739–745.

[43] Jacobs PA, Flanigen EM, Jansen JC, Van Bekkum H. Introduction to Zeolite - Science and Practice. 2001; 11–35.

[44] Jha VK, Hayashi S. Modification on natural clinoptilolite zeolite for its NH_4^+ retention capacity. J. Hazard. Mater. 2009; 169: 29–35.

[45] Mihok F, Macko J, Orinak A, Orinakov R, Kova K, Sisakov K, Petru O, Kosteck Z. Controlled nitrogen release fertilizer based on zeolite clinoptilolite: Study of preparation process and release properties using molecular dynamics. - Curr. Res. Green Sustain. Chem. 2020; 3: 100030.

[46] Prisa D. Particle films: chabazitic zeolites with added microorganisms in the protection and growth of tomato plants (Lycopersicon esculentum L.). GSC Advanced Research and Reviews. 2020; 4(2): 01–08.

[47] Prisa D. Chabatitic Zeolites With Earthworm Humus Added To The Growing Media To Improve Germination and Growth of Horticultural Plants. International Journal of Scientific Research in Multidisciplinary Studies. 2020; 6(5): 24–31.

[48] Kalita B, Bora SS, Gogoi B. Zeolite: a soil conditioner. Int. J. Curr. Microbiol. Appl. Sci. 2020; 9: 1184–1206.

[49] Prisa D. Comparison between sterilized zeolite and natural zeolite in the Cactus Pear (Opuntia Ficus-Indica L. Mill.) growing. GSC Advanced Research and Reviews. 2020; 04(03): 007–014.

[50] Barbarick KA, Lai TM, Eberl DD. Exchange Fertilizer (Phosphate Rock plus Ammonium-Zeolite) Effects on SorghumSudangrass. Soil Sci. Soc. Am. J. 1990; 54: 911–916.

[51] Mohammad MJ, Karam NS, Al-Lataifeh NK. Response of croton grown in a zeolite-containing substrate to different concentrations of fertilizer solution. Commun. Soil Sci. Plant Anal. 2005; 35: 2283–2297.

[52] Kavoosi M. Effects of zeolite application on rice yield, nitrogen recovery, and nitrogen use efficiency. Commun. Soil Sci. Plant Anal. 2007; 38: 69–76.

[53] Ahmed OH, Sumalatha G, Muhamad AN. Use of zeolite in maize (*Zea mays*) cultivation on nitrogen, potassium and phosphorus uptake and use efficiency. Int. J. Phys. Sci. 2010; 5: 2393–2401.

[54] Kralova M, Hrozinkova A, Ruzek P, Kovanda F, Kolousek D. Synthetic and Natural Zeolites Affecting the Physicochemical Soil Properties. Rostlinna Vyroba-UZPI: Praha, Czech Republic. 1994; 126–195.

[55] Desutter TM, Pierzynski GM. Evaluation of soils for use as liner materials: A soil chemistry approach. J. Environ.. 2005; 34: 951–962.

[56] Doni S, Gispert M, Peruzzi E, Macci C, Mattii GB, Manzi D, Masini CM, Grazia M. Impact of natural zeolite on chemical and biochemical properties of vineyard soils. Soil Use Manag. 2020; 1–11.

[57] De Campos Bernardi AC, Oliviera PPA, De Melo Monte MB, Souza-Barros F. Brazilian sedimentary zeolite use in agriculture. Microporous Mesoporous Mater. 2013; 167: 16–21.

[58] Mazur GA, Medvid GK, Grigora TI. Use of natural zeolites for increasing the fertility of light textured soils. Pochvovedenie. 1984; 10: 70–77.

[59] Bouzo L, Lopez M, Villegas R, Garcia E, Acosta JA. Use of natural zeolites to increase yields in sugarcane crop minimizing environmental pollution. In Proceedings of the15th World Congress of Soil Science, Acapulco, Mexico. 1994; 695–701.

[60] Calzarano F, Valentini G, Arfelli G, Seghetti L, Manetta AC, Metruccio EG, Di Marco S. Activity of Italian natural chabazite-rich zeolitites against grey mould, sour rot and grapevine moth, and effects on grape and wine composition. Phytopathol. Mediterr. 2019; 58: 307–321.

[61] Jifon JL, Syvertsen JP. Kaolin Particle Film Applications Can Increase Photosynthesis and Water Use Efficiency of Ruby Red'Grapefruit Leaves. J. Am. Soc. Hortic. 2003; 128: 107–112.

[62] Glenn DM, Erez A, Puterka GJ. Particle films affect carbon assimilation and yield in 'Empire' apple. J. Am. Soc. Hortic. 2003; 128: 356–362.

[63] Abou-Khaled A, Hagan RM, Davenport DC. Effects of kaolinite as a reflective antitranspirant on leaf temperature, transpiration, photosynthesis, and water-use efficiency. Water Resour. Res. 1970; 6: 280–289.

[64] Lateef A, Nazir R, Jamil N, Alam S, Shah R, Naeem Khan M, Saleem M. Synthesis and characterization of zeolite based nano–composite: An environment friendly slow release fertilizer. Microporous and Mesoporous Materials. 2016; 232: 174–183.

[65] Karami S, Hadi H, Tajbaksh M, Modarres-Sanavy SAM. Effect of zeolite on nitrogen use efficiency and physiological and biomass traits of Amaranth (*Amaranthus hypochondriacus*) under water-deficit stress conditions. J. Soil Sci. Plant Nutr. 2020; 20: 1427–1441.

[66] Szerement J, Szatanik-Kloc A, Jarosz R, Bajda T, Mierzwa-Hersztek M. Contemporary applications of natural and synthetic zeolites from fly ash in agriculture and environmental protection. J. Clean. Prod.. 2021; 311: 127461.

[67] Khaleque A, Alam MM, Hoque M, Mondal S, Haider JB, Xu B, Johir MAH, Karmakar AK, Zhou JL, Ahmed MB, Moni MA. Zeolite synthesis from low-cost materials and environmental applications: A review. Environ. Adv. 2020; 2: 100019.

[68] Polat E, Karaca M, Demir H, Onus AN. Use of natural zeolite (clinoptilolite) in agriculture. J. Fruit Ornam. 2004; 12: 183–189.

[69] Türk M, Bayram G, Budakli E, Çelik N. A study on effects of different mixtures of zeolite with soil rates on some yield parameters of alfalfa (*Medicago sativa* L.). J. Agron.. 2006; 5: 118–121.

[70] Khan MZH, Islam MR, Nahar N, Al-Mamun MR, Khan MAS, Matin MA. Synthesis and characterization of nanozeolite based composite fertilizer for sustainable release and use efficiency of nutrients. Heliyon. 2021; 7: e06091.

[71] Rakhimol KR, Thomas S, Kalarikkal NKJ. Nanotechnology in controlled release fertilizers, in: Controlled Release Fertilizers for Sustainable Agriculture. Elsevier. 2021; 169–181.

[72] Li Y, Li L, Yu J. Applications of zeolites in sustainable chemistry. Inside Cosmetics. 2017; 3: 928–949