INFLUENCE OF ZEOLITE DOSES ON GROWTH AND YIELD OF TOMATO VARIETIES

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INFLUENCE OF ZEOLITE DOSES ON GROWTH AND YIELD OF TOMATO VARIETIES

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And Allah is the best of providers

(Surah Al-Jumu'ah-Ayah 11)

DEDICATED TO

MY BELOVED PARENTS

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CERTIFICATE

This is to certify that the thesis entitled **“INFLUENCE OF ZEOLITE DOSES ON GROWTH AND YIELD OF TOMATO VARIETIES”** *submitted to the Faculty of Agriculture, Sher-e-Bangla Agricultural University, Dhaka, in partial fulfillment of the requirements for the degree of* ***MASTER OF SCIENCE in HORTICULTURE****, embodies the result of a piece of credible research work carried out by* ***FATMA JHILIC,*** *Registration No.* ***18-09172*** *under my supervision and guidance. No part of the thesis has been submitted for any other degree or diploma.*

I further certify that any help or source of information, receiving during the course of investigation has been duly acknowledged.

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ABSTRACT

An experiment was conducted at Sher-e-Bangla Agricultural University, Dhaka, Bangladesh during the period from October 2018 to March 2019 to study the influence of different zeolite doses on the growth and yield of tomato varieties. Five tomato varieties viz. Sweden 5 (V_1), Apple Netherland (V_2), TM 0.02 (V_3), Roma-VF (V_4), BARI Tomato-2 (V_5), and three levels of zeolite treatment, no zeolite application (T_0), 12.5 kg/ha (T_1), 18.5 kg/ha (T_2) had been used in this experiment. The experiment was outlined in randomized complete block design (RCBD) with three replications. Significant variation was observed at different growth and yield parameters with different treatments. Among varieties, maximum plant height (138.8 cm), leaf number (77.9/plant), cluster number (7.5/plant), flower number (9.6/cluster), fruit number (42.1/plant), fruit yield (93.1 t/ha) was found from V_1 and minimum fruit yield (80.3 t/ha) was found from V_3. In case of zeolite application maximum fruit number (39.6/plant), maximum fruit yield (88.8t/ha) was recorded in T_2 treatment (18.5 kg/ha). The highest fruit yield (95.5 t/ha) was found from combination V_1T_2 and the lowest yield (78.4 t/ha) was found from combination V_3T_0. It can be concluded that Sweden 5 variety with 18.5 kg/ha zeolite application would be potential for better growth and yield of tomato.

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ABBREVIATIONS AND ACRONYMS

AEZ = Agro-ecological Zone

Agric. = Agriculture

BARI = Bangladesh Agricultural Research Institute

Bio = Biology

CV = Coefficient of Variance

CEC = Cation exchange capacity

DAT = Days after Transplanting

et al. = And others

FAO = Food and Agriculture Organization

i.e. = That is

LSD = Least Significant difference

Res. = Research

Sci. = Science

Technol. = Technology

Viz. = Namely

CHAPTER I

INTRODUCTION

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INTRODUCTION

The cultivated tomato (*Solanum lycopersicum* L.) is the world's most highly consumed vegetable due to its status as a crucial ingredient in a wide variety of raw, cooked, or processed foods. It belongs to the family Solanaceae, commonly known as the nightshade family, which includes several other commercially important species (OECD, 2017).

Tomato generally accepted to have originated in the Andean region of Western South America which is now encompassed the part of Colombia, Chile, Peru, and Bolivia (Peralta *et al.*, 2008; Blanca *et al.*, 2012). Currently, tomato is the crucial point of the horticultural industry and is expanding worldwide either for fresh market or processing.

Tomatoes are filled with all kinds of health benefits for the body and are rich in nutritional substances. Potassium, vitamin C, vitamin E, β-carotene, and fibers that are found in tomatoes are a true healthy spring (Sima *et al.*, 2008). With their excess salt and chemical composition, tomatoes act as alkalines, having major catalytic importance for the human organism (Oshima *et al.*, 1996). One of the most recognized tomatoes eating benefits of its lycopene content which is a vital anti-oxidant that helps to fight against cancerous cell formation and it's not a naturally produced element within the body. While other fruits and vegetables do contain this vital health ingredient, no other fruit or vegetable has the high concentration of lycopene that the tomato takes pride in. Also, tomatoes are good for skin, helping to maintain strong bones due to having a considerable amount of calcium and vitamin K, good for the heart because of the vitamin B and potassium in tomatoes, improving the vision by the vitamin A found in tomatoes (Debjit *et al.*, 2012).

The importance of tomatoes is very significant because these can be consumed fresh, as ingredients of tomato salads or mixed salads, in vegetable soups, sauces, infilled tomatoes, etc., as well as commercially processed as natural juice, chilly juice, cans, and sauces.

According to the UN FAO in 2018-19, Global tomato production is currently around 180.6 million metric ton. The top 5 largest tomato producing countries are China, India, United States, Turkey, and Egypt. They account for 62% of global production. However, according to the UN Comtrade: United Nations International Trade Statistics Database the top 3 exporting countries are Mexico, Netherlands, Spain whose exports share is more than 55% percent. According to the UN FAO and UN Comtrade in 2019, Bangladesh produced 3,87,653 ton tomatoes where exported $39.69K and imported different tomato products worth $13.06M. The amount of import in 2018 & 2017 was respectively $432.68K & $63.93K. This means nowadays the government has to import a huge amount of tomato, tomato seed, tomato sauce, jelly, and jam from foreign countries, especially from India. If a sufficient amount of good quality tomato is produced in our country, then we can save the huge amount of import cost.

Tomato is the most promising industrial crop in Bangladesh which requires essential nutrients in the proper amount for its optimum growth and development. For a higher yield of tomato, rich and fertile soil is necessary. Nutrient loss due to leaching, volatilization, and fixation upon fertilizer application to soils resulted in lower nutrient use efficiency by crop plants which have imposed a negative impact on soil fertility. Moreover, extensive application of chemical fertilizers resulted in low biological activity, deterioration of soil quality, poor moisture-holding capacity, and a severe imbalance of plant nutrients that led to poor use efficiency of applied fertilizers/nutrients in all types of soil (Ge *et al.*, 2010; Loks *et al.*, 2014). Low soil fertility is the single most pervasive constraint to high and sustainable production. The application of excessive high soluble inorganic fertilizers has also resulted in agronomic and pollution problems (Rahman and Zhang, 2018).

As a result, studies on how to employ efficient methods to demote nutrient applications at the same time increasing or maintaining crop yield, reducing nutrient losses, and improving nutrient use efficiency are imperative (Oosterhuis and Howard, 2008). Use of Zeolite may signify an endeavor to answer the drawback of low nutrient retention capacity and nutrient leaching which causes low crop yields and soil contamination.

Studies on zeolites are increasing because of their high cation exchange capacity which subsequently increases soil fertility (Ramesh *et al.*, 2015), their rapid dehydration-rehydration, adsorption and molecular sieving properties, promise to contribute significantly to agricultural technology.

The high ion-exchange and retention ability of natural sedimentary zeolites (in particularly clinoptilolites) as well as their high adsorptive affinity for water have contributed to their successful applications in plant growth. Zeolites help to retain nutrients in the root zone to be used by the plants when required. Consequently, this leads to more effective use of fertilizers by reducing their rates for the same yields, by prolonging their activity, or finally by producing higher yields (Demir *et al.*, 2004).

Zeolite is a hydrated crystalline aluminosilicates (AlO_4 and SiO_4) of alkali and alkaline earth cations with 3 - dimensional framework characterized by pores and channels (Notario *et al.*, 1995). The pores are interconnected and form long wide channels of different sizes depending on the mineral. These channels allow easy movement of the ions and molecules into and out of the structure. Zeolites have large vacant spaces or cages within and resemble honeycomb or cage-like structures. The Swedish chemist and mineralogist Axel Fredicka Cronstedt discovered the first zeolitic mineral, stilbite, in 1756. This natural mineral intensively loses water when heated and that's why named it using the Greek words: dzeo boil and lithos stone, rock. (Polat *et al.*, 2004).

Currently, there are over 40 known types of natural zeolites, but only seven of them (clinoptilolite, chabazite, analcime, erionite, ferrierite, mordenite, philipsite) are being exploited. Global production of natural zeolite is estimated at 3.2 million metric tons. China produces more than 70% of it.

Zeolites are characterized to hold a high ability to lose and gain water and to exchange cations without a major change in its structure (Mumpton, 1999; Kithome *et al.*, 1999). Zeolites when applied with conventional fertilizers acts as an ion exchanger and molecular sieve, trapping the nutrient molecules from applied fertilizer in the void spaces in its structure and slowly release it to plants. Thus less nutrient loss occurs due to nutrient leaching, which ensures improved nutrient use efficiency and also reduces groundwater contamination.

Out of the many properties of zeolites some of the prominent ones include increase in soil CEC, act as a reservoir of NH_4^+ and K^+ (Hershey *et al.*, 1980) and increase in the water-holding capacity of loamy sand soils (Huang and Petrovic, 1994). Water molecules could be easily dehydrated or reabsorbed in the pores of zeolite molecule which help to provide prolonged moisture during dry periods; and also improve the lateral spread of water into the root zone during irrigation.

In agriculture, zeolites have diverse applications, as slow-release fertilizers, soil conditioners, heavy metal removers, increasing the nutrient and water use efficiency. Soil macronutrients i.e. nitrogen, phosphorus, and potassium can be provided to plants in the form of ammonium (NH_4^+) and Phosphate (P) exchanged zeolites. One of the most prominent utilization of zeolites in agriculture is the slow/controlled-release fertilizer feature. The widespread affluence of Clinoptilolite, Chabazite, Phillipsite, and Mordenite in nature and their selectivity for certain cations (i.e. NH_4^+ and K^+) makes them suitable for slow-release fertilizer feature. Zeolites are broadly utilized as soil conditioners to enhance soil physio-chemical properties (Kralova *et al.*, 1992). Unlike other soil amendments (e.g. lime) zeolite does not break down over time but remains in the soil to enhance nutrient retention. Therefore, its addition to the soil will save the quantity of water and fertilizer needed, by retaining beneficial nutrients in the root zone. It is claimed to improve plant performance by reducing nutrient leaching and utilizing nutrients and water more efficiently which have a profitable effect on the overall growth and yield of tomato.

Objectives:

1. To study the growth and yield performance of different tomato varieties.
2. To study the influence of different zeolite doses on the growth and yield of tomato varieties.
3. To study the combined effect of tomato varieties and zeolite doses on the growth and yield of tomato.

CHAPTER II

REVIEW OF LITERATURE

CHAPTER II

REVIEW OF LITERATURE

Tomato (*Lycopersicon esculentum*) is a popular vegetable across the globe and the most important ingredient in enhancing the taste and flavor of other vegetables. Increasing the productivity of agricultural crops like tomatoes with good yield and quality is an important goal of the growers for market and export. To meet up the demand, irrational use of fertilizer has resulted in considerable nutrient loss through leaching. This arises several problems like low nutrient use efficiency, increasing fertilizer doses as well as input costs and groundwater contamination as well as environmental pollution. Zeolite can be applied as a solution to these issues due to its special features like high cation exchange capacity, rapid hydratation-dehydratation, and molecular sieve action. Nutrient and water molecules are trapped in the void spaces of the tetrahedral open cage-like structure of zeolite which is then slowly released to the plant root zone. This reduces nutrient leaching which helps to obtain improved nutrient and water use efficiency and ultimately producing a better yield. Some research works related to zeolite and its potential use in different crops have been presented in this section.

Nisreen and Radi (2020) studied the effect of ground and natural zeolite on the growth and yield of wheat. The study investigated the effect of five levels of zeolite (0%, 1%, 2%, 3%, and 4%) for both natural and platforms. The experiment was laid out by designing the completely randomized sections with three replicates. The use of zeolite in both its natural form and the mill resulted in increasing the properties of the plant height (by 53.20% for ground zeolite and 40.61% for natural zeolite), the area of the flag leaf (64.02 cm^2 4% normal zeolite), the number of stools and the chlorophyll content significantly. Zeolite application improved the number of spikes, the number of grains, the number of spikes, and spike length, and had a positive effect of 1000 Beans and bio-yield and grain.

A pot experiment was conducted by Salako *et al.* (2020) to evaluate the efficacy of the synthesized zeolite A based fertilizer on the growth and fruit yield of two cultivars of tomato (Roma VF and UC82B). The experiment was designed in a completely randomized design (CRD) with three replications. Application of the synthesized zeolite A based fertilizers and NPK 15:15:15 at four levels of treatment (soil alone 0% as control, 0.66 g, 1.33 g, 2.66 g which is equivalent to 0, 150, 300, and 600 kg/ha) took place 5 weeks after transplanting. At the 11 WAT, the zeolite A based fertilizer treated plants were observed to have greener leaves than the plants treated with NPK fertilizer. The zeolite A based fertilizer released its nutrients slowly for a longer period than the conventional fertilizers. In the conventional NPK fertilizer, nutrient carriers or fillers have no adherence to the plant nutrients and therefore nutrients leach easily beyond the root zone with percolated water. The consequence is the cutting off of the supply of nutrients to the leaves. The result of a higher leaf count (growth parameter) of zeolite A based fertilizer with a mean (54.2) compared with NPK 15:15:15 with a mean (25.7) at 11 WAT indicated the slow release feature and nutrient retention of zeolite A based fertilizer. The zeolite A based fertilizer treated plants had a higher fruit yield with a mean (84.69) compared with NPK 15:15:15 fertilizer with a mean (69.34). The result indicated that plant nutrients might have leached beyond the root zone in the NPK fertilizer when nutrients were utilized in the zeolite A based fertilizer to give higher fruit yields.

Beyki and Khashei (2019) experimented in the 2018 cropping season to study the effect of the interaction of water stress and different levels of zeolite on the growth and yield characteristics of the black cumin plant (*Nigella sativa* L). For this reason, designed a completely randomized block as split plots, with irrigation at two levels (irrigation with 100% (I_1) and 50% (I_2) water requirement, respectively) and using potassium zeolite treatment as Z_0 (without zeolite), Z_1 (2 $g.kg^{-1}$ soil) and Z_2 (4 $g.kg^{-1}$ soil) respectively, with three replications. Under the influence of interaction between zeolite and irrigation management, the highest plant height was 16.88cm and weight of fresh, dry yield and 1000-seed were, respectively, 11.96, 9.33, and 13.19 g. Also, the number of capsules per plant and seeds per capsule were, respectively, 10.11 and 52.44. The maximum grain yield was 874.77 $kg.ha^{-1}$ and water use efficiency (WUE) was 0.135 $kg.m^{-3}$, respectively. The lowest values for the corresponding parameters were 13.13 cm, 7.4, 5.05, and 11.95 g, respectively, and 8.33 and 44.44 for the number of capsules per plant and seeds per capsule, the yield of 748 $kg.ha^{-1}$ and WUE of 0.118 $kg.m^{-3}$. Though water stress led to a decrease in the characteristics of growth and the yield of black cumin, suggested that it can be maximized under full irrigation of the plant and the application of zeolite at high levels (15 tons per hectare).

Junlin *et al.* (2019) studied the influence of zeolite and phosphorus applications on water use, P uptake, and yield in rice under different irrigation managements. A two-year lysimetric experiment laid in a split-split plot design was conducted to examine the effects of zeolite (0 or 15 t/ha) and P (0 or 60 kg/ha) on water use, P uptake, and grain yield in rice under two irrigation management systems (continuous flooding irrigation (CF) and improved alternate wetting and drying irrigation (IAWD)). Applications of zeolite or P alone improved grain yield, WUE, soil available P, and stem, leaf, and panicle P concentration, and aboveground P uptake. The zeolite application induced more effective panicles, spikelets per panicle, and 1000-grain weight relative to the no-zeolite control and thus increased grain yield by 12.0% in 2016 and 7.8% in 2017. The enhanced grain yield provoked by zeolite was linked to the increase in aboveground P uptake. The zeolite application heightened NH_4^+-N retention in the topsoil and prevented NO_3-N from leaching into deeper soil layers. Moreover, lower rates of P fertilizer possible in paddy fields by zeolite application, mitigating pollution due to excessive P. These results suggest that the combined application of zeolite and P under an improved AWD regime reduced water use, improved P uptake, and grain yield in rice, and alleviated environment risk.

Jakkula *et al.* (2018) reported that fertilizer usage in developing countries has revealed a steady increase over the last few decades. The use and production of N fertilizers contribute to about 60% of the total release of reactive N. More farm subsidies and lower N fertilizer prices have further increased N inputs. Improper fertilization patterns and unbalanced use of N fertilizer have resulted in considerable N losses through ammonia NH_3 volatilization and NO_2 leaching. This has implied that NUE has been as low as ~35%. An efficient crop nutrient management is an important practice and thus, new designer or smart N fertilizers technologies are needed to support the increasing demand and avoid the low nitrogen use efficiency (NUE). The ammonia nitrogen volatilization and nitrate leaching can be reduced or prevented by the use of zeolite carrier material applications that have N in their framework and act as slow/controlled-release fertilizers. These materials will reduce ammonia volatilization and nitrate leaching and at the same time increase crop yield. Zeolites are also identified for their water holding capacity and in drylands, they are the most suitable fertilizers to lengthen moisture levels in severe drought-like conditions. In addition to macronutrients, micronutrients can also be introduced into zeolites which can supplement nutrient-deficient soils. Thus, zeolites along with improving yield can also boost the nutrient and water use efficiency of drylands.

Zeolites find a large number of potential applications in agriculture, particularly in soil management, wastewater treatment, and heavy metal pollution removal. Studies have shown that zeolites significantly adsorb NH_4 and P after the dissolution of applied chemical fertilizers or decomposition of manures and cover crops and minimize reactive NO_3 formation and also could be effectively used for wastewater treatment as well as cleaning of heavy metal polluted sites. They can be used either as carriers of nutrients and/or medium to free nutrients to increase nutrient use efficiency. Usage of zeolites is expected to reduce a third to half Urea-N fertilization. Zeolites are effectively used as soil ameliorants for treating salinity and have a positive effect on soil fertility. Acting as slowly soluble fertilizers, they improve water balance and sorption characteristics of light sandy soils, which is reflected in higher yield and better quality. Also, zeolites improve the efficiency of water and nutrient use of plants and decrease runoff and sediment amount by increasing the soil water holding capacity. In drylands, as rainfed agriculture experiences drought year after year, the use of zeolites which increases the water holding capacity of various soil types could be alternatives to conventional fertilizers. Finally, zeolites can serve as future environmentally friendly materials for both increasing crop yield and reducing agriculture input costs.

A study conducted by Ozbahce *et al.* (2018) to examine the effect of the application of different doses of the natural zeolite clinoptilolite and different irrigation levels on the yield and quality of potatoes (*Solanum tuberosum* L.), cv. Agria, and the soil nutrient contents under water-deficit stress in Konya-Karapınar, Turkey. The study was designed in a split-plot design with three replications. The main factor was the zeolite dose (Z_0: 0, Z_3: 30, Z_6: 60, Z_9: 90, and Z_{12}: 120 t ha^{-1}) and the subfactor the irrigation level (I_{50}: 0.50, I_{75}: 0.75 and I_{100}: 1.00). In I100 treatment, irrigation was applied to load 0–60 cm soil-depth until field capacity. In other treatments (I_{75}-I_{50}), it was given up to 75 and 50% of the water applied to I_{100} treatment at 6-day intervals. The amounts of irrigation water were determined by class-A pan evaporation using the canopy area. For potato tuber yield, different quality characteristics, and certain nutrient element content in the soil, significant interaction occurred between zeolite doses and irrigation level ($P < 0.01$). The highest crop yields, 33.9-39.1 and 33.5-34.3 $kgha^{-1}$, respectively, were obtained from Z_6I_{100} and Z_6I_{75} applications in both years. There were no significant differences between these two treatments and also some other treatments (Z_3I_{100}, Z_9I_{100}, and $Z_{12}I_{100}$). In the experimental years, water consumption of Z_6I_{75} treatment was found as 509 and 420 mm, respectively. Some physical and chemical contents (the cation exchange capacity - CEC, exchangeable sodium percentage - ESP, and total P, K, Ca, Mg, Zn, and Mn contents) of the experimental soil were influenced by zeolite treatments. These results revealed that certain zeolite doses with optimum irrigation can be beneficial for potato grown in water-deficit stress conditions because of positive impacts on some soil physical and chemical properties and crop quality.

Yuvaraj and Subramanian (2018) conducted an experiment to develop slow-release Zn fertilizer using nano-zeolite as a carrier. Zinc (Zn) use efficiency hardly exceeds 2–3% and a major portion of added Zn gets fixed in the soil. To enhance the Zn use efficiency by crops, a laboratory study was initiated at the Department of Nano Science and Technology, Tamil Nadu Agricultural University, Coimbatore, India, to develop Zn fertilizer using nano-zeolite as a substrate. The natural zeolite (clinoptilolite) was ball milled to obtain nano-dimension (90-110 nm) and fortified with Zn by loading Zinc sulphate ($ZnSO_4$). Instruments like particle size analyzer, Fourier Transform Infrared Spectroscopy, Raman Spectroscopy, X-ray Diffraction, Scanning Electron Microscope, and Transmission Electron Microscope was used to characterize zeolite before and after loading of Zn. The data indicated that the nano-zeolite was loaded successfully loaded with Zn to the tune of 14% and Zn presence in the substrate was confirmed by Energy-dispersive X-ray spectroscopy and Atomic Force Microscopy. After the synthesis, the sorption and desorption pattern of Zn of the nano-zeolite was examined using a percolation reactor. The results revealed that Zn release from the nano-zeolite substrate has prolonged for 1,176 hrs, while the Zn released from the ordinary $ZnSO_4$ halted to exist within 216 hrs. The data suggest that the nano-sized zeolite is able of retaining Zn and slowly release into the soil solution, which may be served as a slow-release Zn fertilizer and improve the Zn use efficiency by crops.

Zheng *et al.* (2018) conducted an experiment to find out the effects of zeolite application on grain yield, water use, and nitrogen uptake of rice under alternate wetting and drying irrigation. A two-year lysimetric experiment was carried to assess the effects of zeolite application (Z_0: 0 and Z_1: 15 t/hm^2) and water regimes (W_0: continuous flooding irrigation, W_1: energy-controlled irrigation, W_2: alternate wetting and drying irrigation) on rice grain yield, water use, and total nitrogen uptake. Zeolite addition to rice field significantly increased grain yield (10.80 t/ha), total N uptake (92.57 kg-hm^{-2}, and water use efficiency (WUE) (1.35/kg-m^{-3}). There was a significant interaction between zeolite application and water regimes on water consumption and WUE. Z_1W_1 treatment obtained the highest water use efficiency (WUE). The combined Z_1 and W_1 treatment increased spike and root dry weight, effective panicles, spikelets per panicle, and 1000-grain weight, all of which contributed to better grain yield, and consequently improved WUE and total N uptake with the decreased water consumption by W_1 treatment and enhanced N retention by zeolite addition. It is concluded that the combination of zeolite application at the rate of 15 t/hm^2 and energy-controlled irrigation could be recommended to favor farmers by curtailing irrigation water while improving grain yield on a clay loam soil.

Caroline *et al*. (2017) studied the beneficial effects of zeolites on plant photosynthesis. A distinct trend could be observed for the treated apple trees, i.e. a rise of photosynthesis rate was noted after treating the apple trees with the zeolites, followed by a decrease after two weeks. In addition to the impact of zeolites against plant diseases and insect pests, zeolites may also have a beneficial impact for the treated plant itself. Zeolites can adsorb CO_2, which may influence photosynthesis. Zeolites may also lessen leaf temperature by reflecting the infrared radiation. These properties lead to a reduction of transpiration rate, which may enhance the water-use efficiency, yield, and fruit quality.

An experiment was conducted by Hazrati *et al.* (2017) on the effects of zeolite and water stress on growth, yield, and chemical compositions of Aloe vera L. For this purpose, randomly, 20%, 40%, 60%, and 80% of the field capacity (FC) and zeolite (0, 4, and 8 g kg^{-1} soil) were used to determine the effect of water stress and zeolite on chemical compositions, growth, and yield of Aloe vera. After imposing the treatments, the plants were harvested at 90, 180, and 270 days. The plants irrigated respectively 20% and 40% FC with 8 g zeolite produced the greatest number of new leaves and pups. However, the maximum weight of fresh leaf and the fresh gel was observed after 270 days of plant irrigation by depleting 40% of the FC and treated with 8 g zeolite. The results indicated, with less water and more zeolite availability, the water use efficiency of Aloe vera increased. Also, without zeolite application, maximum aloin and proline accumulation obtained 90 days after imposing the treatments during plant irrigation after depleting 80% and 60% of the FC, respectively, and irrigation after 80% depletion of the FC resulted in the highest fructose and glucose content. Therefore, zeolite application could alleviate water stress adverse effects, and improved plant growth and yield.

A 2-year field experiment using a strip-plot design was conducted by Taotao *et al.* (2017) to evaluate the impact of zeolite (Z) amendment on yield performance, quality characteristics, and nitrogen (N) use efficiency of paddy rice. Japonica rice (cv. Gangyu 6) was cultivated in a silty loam soil with Z amendment (0, 5, 10, and 15 t Z ha^{-1}) as strip plots and N application (0, 52.5, 105.0, and 157.5 kg N ha^{-1}) as whole plots. Compared with the paddy field without Z amendment, there was 14.2 to 35.8% higher potential postharvest residual soil mineral N and 20.1 to 44.6% higher exchangeable potassium when the top 30 cm of the soil was amended with 5 to 15 t Z ha^{-1}. Application of 5 to 15 t Z ha^{-1} increased applied N fertilizer use efficiency by 39.0 to 64.4% and N recovery efficiency by 20.7 to 85.2%, respectively. Milling, appearance, and eating quality traits were not affected by Z amendment, whereas rice protein content was increased by Z addition. The enhanced yield performance due to Z was mainly caused by improved essential plant-available nutrients, which reduced ineffective tillers and produced a more effective tiller number per square meter at harvest. Soil chemical properties, yield performance, N uptake, and N use efficiency were significantly enhanced by zeolite amendment. Paddy fields amended with Z improved grain yield. The upper 30 cm profile soil amended with Z resulted in higher potential postharvest RSMN and exchangeable potassium due to enhanced CEC. Improved essential plant-available nutrients led to higher N uptake and increased effective tillers through reducing the ineffec-tive tillers and therefore improved grain yield. None of the milling, appearance, and eating quality traits were significantly altered by Z amendment, whereas rice protein content was increased by Z. Zeolite-based practices for lowland rice production systems have the potential to meet the dual challenges of food security and sustainable development.

Sangeetha and Baskar (2016) reported that in many parts of the world food security is being affected due to the declining quality and/or quantity of soil resources and climate change. Also, there is a rising interest in the use of nanoporous zeolites in farming over the years because of current public concern about the adverse effects of chemical fertilizers on the agro-ecosystem. In this context, farming with zeolites has pulled attention. Zeolites are natural aluminosilicates present in rocks in different parts of the world. The use of zeolite has gained momentum in the recent past owing to the number of benefits acquired from them. Zeolites are beneficial in agriculture due to their large porosity, cation exchange capacity, and selectivity for ammonium and potassium cations. They can be utilized both as carriers of nutrients and as a medium to free nutrients. Ion-exchange properties of zeolites are identified as important for plant nutrition due to their high cation-exchange capacity and porosity. The specific structure and diversity of the zeolites vary as also their application. Considerable research has been carried out globally to exploit the potential of zeolites in the continual maintenance of soil productivity. The current growing awareness and availability of inexpensive natural zeolites have aroused considerable commercial interest. Although considerable research has been advanced, further research needs to be carried out for their efficient utilization in agriculture.

Aynur *et al.* (2015) studied the effects of different zeolite doses (Z_0: 0, Z_3: 30, Z_6: 60, Z_9: 90, and Z_{12}: 120 t ha^{-1}) and water levels (I_{50}: 0.50, I_{75}: 0.75, and I_{100}: 1.00) on yield, quality, and nutrient absorption of common bean under arid conditions. The experiment was designed in a split-plot design with three replications. The results revealed that in each treatment, different doses of zeolite together with changes in the rate of irrigation levels influenced yield and yield components. Zeolite and irrigation treatments also affected water use efficiency. Z_9I_{100} treatment produced the highest yields, 4777 and 4114 kg ha^{-1}, respectively, in 2011 and 2012. During the experimental years, water consumptions were determined 451 and 468 mm, respectively at the same treatment. In addition to this, zeolite applications affected the uptake of some macro and micronutrients by plants. Specifically, zeolite increased N, K, Zn, Mn, and Cu content in plant tissues ($p < 0.05$). These nutrient levels increased with increasing zeolite doses. The results from this research presented some beneficial effects of zeolite as a soil amendment on crop production.

Ramesh *et al.* (2015) studied the effect of zeolites on soil quality, plant growth, and nutrient uptake efficiency in sweet potato (*Ipomoea batatas* L.). Also, he studied the effectiveness of NPK uptake by using zeolites. For this purpose, synthetic zeolites viz. fly ash based near-neutral agricultural grade (FAZ) and commercial (CZ) zeolites (zeolite 4A) in different combinations were used. The experiment was conducted in a completely randomized design (CRD) with six treatments viz. FAZ applied at 1% and 2% levels (w/w, zeolite: soil) (denoted as F_1 and F_2), pH treated CZ at 1% level, potassium and zinc impregnated CZ (KCZ and ZnCZ) at 1% level, and a control (without zeolite).

The study showed that the pH buffering effect and beneficial action of zeolites based (F_1, F_2, KCZ, ZnCZ) in maintaining a near-neutral pH condition compared to control for the successful cultivation of sweet potato. Among the treatments, electrical conductivity (EC) values are well below the safe limits (4 dSm^{-1}). 1% zeolite amended soils registered a better soil moisture increase over control to an extent of 20.9% and tuber yield increase of 57% over control. However, the excess sodium content of pH treated commercial zeolites (CZ) having advantages in moisture-holding (24.1%) and cation exchange properties (3.6 cmol kg^{-1}), had a negative influence on plant growth and yield. Soils amended with both FAZ levels are well below the critical limits in terms of SAR. Though additions of fly ash zeolites to the soil at 2% level was found to benefit soil exchangeable K (26.9 mmol kg^{-1} > 12.9 mmol kg^{-1}), the number of branches (11.6 > 10.4), total uptake of potassium (6.10 g/plant > 4.54 g/plant), and high nutrient uptake efficiency as compared with 1%, the tuber yield among the two treatments were on par (177 g/plant of F_1 & 167.7 g/plant of F_2). The uptake efficiency of FAZ amended at 1% (F_1) rate was significantly superior in respect of N (214.1% F_1, 148.0% F_2, and 85.8% C) and P (337.5% F_1, 142.2% F_2, and 49.8% C) as compared to F_2 and control. Hence the application of fly ash zeolites to soils at a 1% rate could be beneficial for sweet potato production in laterite soils. The study also indicated the scope of utilizing the fly ash based zeolites as a slow-release fertilizer for which intense studies on charge persistence and its relationship with nutrient holding properties in respect of NH_4^+, K^+, Ca^{++} has to be taken up in order to effectively utilize this soil conditioner for better tuber crops production especially in low-quality soils.

Avagyan *et al.* (2013) investigated the effect of natural zeolites and its mixtures with different fertilizers on the yield of green kidney beans. According to the data obtained in the experiment, the use of zeolites not only promotes rapid germination in the first weeks of plant growth but also increase crop yields (34 pods per plant on average) relative to control plants - 25 pods per plant, increases in the same time the resistance of plants to disease. Plants grown on the zeolites are more powerful and higher, the mixture of soil and zeolite (1kg/m^2) provides good growth in height and a large number of leaves. Plants growing on the mix of soil with zeolites in concentration 0.5 kg/m^2 were bushy gave a lot of cuttings and 5-6 beans per cutting. It has been noted that the best use of zeolite is its addition to the soil at the rate of 5t/ha which increased green bean yields, raised their resistance to drought, and increased protein content in beans. Zeolite saves and ensures the gradual emergence of essential nutrients from the pores, increases overall crop yields, and provides a solid reservoir of nutrients, allowing farmers to reduce the amount of fertilizer and at the same time improve productivity. Thus, rationality and high efficiency of the zeolite in low concentrations provides a high yield, ecologically pure healthy foods enriched with protein, even in arid areas.

Ghanbari and Siavash (2013) studied the effect of different rates of zeolite and water deficit in peppermint (*Mentha piperita* L). The experiment was conducted based on a randomized complete block design with three replications in the institute of agriculture research at the University of Zabol, Iran. Factors were considered as three levels of drought stress (70ü, 50ü, 30ü) and four levels of zeolite (0, 1.5, 2, 2.5 g/ 1kgsoil). Analysis of variance pointed that all of the growth parameters and essential oil yield were affected by drought stress and zeolite application. Drought stress motivated a significant reduction in all growth parameters except oil percentage. However, Zeolite application improved the mean of all traits. Results for interaction effects presented that zeolite application in drought stress elevated the means of all traits. Analysis of variance for essential yield disclosed that the highest oil yield was obtained by drought stress 50ü and 2.5 g zeolite. It seems that, in drylands that are exposed to drought stress, zeolite application can be helpful for growth parameters and oil yield improvement and prevention of decrease in oil yield. Zeolite application can improve shoot yield and oil yield under drought stress conditions and it can persist less damaging of drought stress in medicinal and aromatic plant farming. Zeolite may be recommended for the soil in arid and semi-arid regions to increasing drought tolerance in medicinal and aromatic plants.

Zhaohui *et al.* (2013) reported that there has been a great need to reduce the non-point source pollution due to pesticide and fertilizer applications. With a large surface area and high cation exchange capacity, zeolite was proposed to utilize as carriers to control ammonium and potassium release. A greenhouse test was performed to evaluate spinach growth and spinach quality after application of zeolite pre-loaded with ammonium (NH_4^+) and potassium (Eco-zeolite). A raise in spinach yield with comparable vitamin C content was gained using the Eco-zeolite. However, elevated oxalate content was unexpected, which may be possible due to the presence of NH_4^+ as the exchangeable cations after modification.

Ebrahim *et al.* (2011) carried out an experiment to examine the effect of zeolite application and nitrogen fertilization on yield and yield components of cowpea. The experiment was conducted in a randomized complete block design with three replications in Astaneh Ashrafiyeh Township (north of Iran) in 2011. Factors of the experiment were consist of two levels of zeolite (Z_1: without zeolite application and Z_2: zeolite application 5 t/ha) and six levels of nitrogen fertilization (N_1: control (0 kg/ha pure nitrogen + without inoculation), N_2: 30 kg/ha pure nitrogen, N_3: 60 kg/ha pure nitrogen, N_4: nitroxin inoculation, N_5: 15 kg/ha pure nitrogen + nitroxin inoculation, N_6: 30 kg/ha pure nitrogen + nitroxin inoculation). At the time of harvesting, seed yield, number of pod per plant, number of seed per plant, plant height, pod length and 100 seed weight were measured. Results showed that the effect of zeolite application had a significant influence on all measured traits. The highest amounts of Seed yield treatment with 835.8 kg/ha, number of pod per plant with 40.2 pods, number of seed per plant with 528.1 seeds, Plant height with 65.7 cm, Pod length with 13.5 cm, and 100 seed weight with 10.3 g was obtained by zeolite application (Z_2). The maximum seed yield between interaction levels was found from the Z_2N_3 treatment with 1224 kg/ha.

Majid *et al.* (2011) conducted a field experiment in 2006-2007 to determine the impact of zeolite on nitrogen leaching and canola production. Four nitrogen (N) levels (0, 90, 180, and 270 kg ha^{-1}) and three zeolite amounts (3, 6, and 9 t ha^{-1}) were applied as treatments. The results exhibited that the highest growth parameters and seed yield were attained with 270 kg N ha^{-1} and 9 t zeolite ha^{-1}. However, the highest and the lowest seed protein percentage and oil content were attained with 270 kg N ha^{-1} accompanied by 9 t zeolite ha^{-1}, respectively. Nitrate concentration in drained water was influenced by nitrogen and zeolite. The lowest and highest leached nitrate values were noted in control without N and zeolite (N_0Z_0) and in treatments with the highest N supply without zeolite ($N_{270}Z_0$), respectively. In general, nitrogen-use efficiency declined with an increase in N supply. Application of 9 t zeolite ha^{-1} showed higher nitrogen use efficiency than other zeolite amounts. Also, the application of more N fertilizer in soil reduced nitrogen uptake efficiency. In total, the application of 270 kg N ha^{-1} and 9 t zeolite ha^{-1} could be suggested as superior treatment.

Due to the increasing demands for environmental protection and sustainable food production, there is no alternative to the requisite use of natural and non-toxic materials for agriculture. For this purpose, Malekian *et al.* (2011) investigated the probability of using surfactant-modified zeolite (SMZ) comparatively with zeolite clinoptilolite (Cp) application to lessen nitrate leaching and enhance crop growth. Also, evaluated the impacts of size (millimeter and nanometer) and application rate (20 g kg^{-1} and 60 g kg^{-1}) of Cp and SMZ response on nitrate leaching and crop. Measuring with the soil lysimeters, the maximum and mean nitrate concentration in the leachate of SMZ-amended soil were determined significantly ($p < 0.05$) lower than those of Cp-amended soil. At the higher application rate of 60 g kg^{-1}, the amount of NO_3-N leached from SMZ- and Cp-amended lysimeters were respectively about 26% and 22% lower than that from the control system. Though there was no significant effect due to the particle size of the two soil amendments, the mean grain yield, grain nitrogen content, stover dry matter, and N uptake were significantly greater in Cp-amended than SMZ-amended lysimeters. In the experiment, it was evident that Plants may have a better response if Cp is used as a fertilizer carrier rather than SMZ when applied at a rate of 60 g kg^{-1}.

A pot study was conducted by Ahmed *et al*. (2010) to investigate if the use of inorganic fertilizers together with zeolite will improve nitrogen (N), phosphorus (P), and potassium (K) uptake and efficiency in maize (*Zea mays*) cultivation on Nyalau series (Typic Paleudalts). Maize hybrid no. 5 variety was used as a test crop. Treatments assessed were: (i) T_1, (Unfertilized condition), (ii) T_2, normal N, P and K application (7.4 g urea + 11.3 g Christmas Island rock phosphate (CIRP) + 3.8 g murate of potash (MOP)), (iii) T_3 (135 g zeolite + 5.92 g urea+9.0 g CIRP + 3.0 g MOP), (iv) T_4 (270 g zeolite + 4.44 g urea + 6.8 g CIRP + 2.3 g MOP), (v) T_5 (405 g zeolite + 3.0 g urea + 4.5 g CIRP + 1.5 g MOP) and (vi) T_6 (540 g zeolite + 1.5 g urea + 2.3 g CIRP + 0.8 g MOP). The effect of T_2, T_3, T_4, T_5, and T_6 on soil N, P, and Mg at harvest did not differ significantly compared with T_1. However, treatments with zeolite significantly enhanced soil K and Ca contents compared to T_1. Irrespective of treatment, dry matter production was not altered. However, nutrient concentrations determined in plant tissues were affected by the zeolite addition. N, P, and K uptake differed significantly but T_6 significantly affected the use efficiency of N, P, and K. The use of inorganic fertilizers mixed with zeolite remarkably enhanced N, P, and K uptake, and their use efficiency in leaves, stem, and roots. The use of zeolite could be beneficial concerning nutrient retention in soil and their use efficiency. The addition of zeolite affects soil chemistry. In terms of N, P, and K uptake in plant tissues, T_3 and T_6 had significant effects, while irrespective of treatment, dry matter production was similar. Generally, all the treatments with zeolite improved N, P, and K uptake and use efficiency in comparison with control treatment. The highest zeolite dose (T_6) significantly increased N, P and K use efficiency of maize hybrid number 5 variety. The use of zeolite in maize cultivation on acid soils could be beneficial.

İlker *et al.* (2010) studied the effects of zeolite utilization with the mixture of different growing media on the seedling quality and nutrient contents of tomato (*Solanum lycopersicon* cv. Malike F1) under the greenhouse conditions. The experimental design was randomized blocks with four replicates and 45 seeds were used for each replicate. For this purpose, natural zeolite, perlite, turf and their different mixtures were used as growing media for tomato seedlings growth. Treatment combinations were GM_1 % 100 turf, GM_2 % 80 turf + % 20 zeolite, GM_3 % 80 turf + % 20 perlite, GM_4 % 60 turf + % 40 zeolite, GM_5 % 60 turf + % 40 perlite, GM_6 % 50 turf + % 25 zeolite + % 25 perlite, GM_7 % 100 zeolite, GM_8 % 100 perlite. As a result of this study, the effects of growing media on the seedling quality parameters were found to be significant and turf + zeolite mixture found to produce best result on the seedling height(5.73 cm), seedling fresh weight(0.60 g) and N(3.30%), P(0.67%), K(3.09%), Ca(3.96%), Mg(0.90%), Fe(228%), Zn(158%), Mn(66.2%) and Cu(24.4%) content. The nutrient contents of seedlings exhibited significant variations ($p<0.001$). Therefore, it was determined that turf +zeolite mixtures could be employed as better alternative media instead of turf + perlite mixtures.

Viorel and Gheorghe (2010) studied the effect of zeolites use on the yield components of greenhouse cultivated tomato. The experiments were organized by using the randomized blocks method with four repetitions. In order to show the impact of culture substrate composition upon the average production of each plant two factorial experimental design model was used. Factor A (tomato hybrids) with 2 gradations: a_1 - Venezia F1; a_2 - Klass F1. Factor B (substrate mixture) with 5 gradations: b_1 (Mt) - 50% manure, 40% garden soil and 10% sand; b_2 - 40% manure, 40% garden soil, 10% peat and 10% sand; b_3 - 50% manure, 10% garden soil, 10% peat, 5% sand and 25% zeolite; b_4 - 20% manure, 20% garden soil, 5% peat, 5% sand and 50% zeolite; b_5 - 10% manure, 5% garden soil, 5% peat, 5% sand and 75% zeolite. Adding zeolite in the composition of the culture substrate for the cultivation of tomatoes cultivated in greenhouses contributes to the obtaining of higher average yield per plant compared to the classical variants (50% manure, 40% garden soil and 10% sand). The higher yield was obtained in substrate mixture in case of using 25% zeolite in the substrate compositions; increase is of 13-18%. Significant positive effects on yield were obtained in variant b_3 (50% manure, 10% garden soil, 10% peat, 5% sand and 25% zeolite). Using the zeolite in soil mixtures represents an alternative to the classical nutritive substrate, composed of those of three or four bases of organic and inorganic components.

Baninasab (2009) researched the impacts of natural Iranian zeolite on the growth and nutrient status of radish (*Raphanus sativus* L. cv. Cherry Belle). The experiment was accomplished in a completely randomized design with six treatments (0, 20, 40, 60, 80, or 100 g zeolite kg^{-1} soil) and four replicates. It's evident from the study that the leaf number and leaf area, shoot fresh weight (FW), the diameter and FW of edible roots, the number, length, and FW of fibrous roots, and harvest index increased by the use of zeolite. Also, the unique properties of natural zeolites pronounced a positive effect on vegetative growth in radish by increasing the concentrations of nitrogen (N) and potassium (K) in shoot tissues, and the cation-exchange capacity of the medium. Thus, the zeolite may be promoted in agriculture for vegetable crops as a soil amendment such as radish to reduce nutrient leaching.

Hossein *et al.* (2009) conducted an experiment to study the effect of zeolite soil application and selenium foliar application on growth, yield, and yield components of three canola cultivar under conditions of late-season drought stress. The experimental design was a randomized complete block arrangement in a factorial split-plot with three replications. There was a significant difference in all traits between zeolite application and non-application. Zeolite application in lands that are exposure to late-season drought stress can keep soil water content and improve plant growth and production. Plant height and number of branches in the plant were increased by zeolite application. It was shown that canola cultivars were different in all of the studied traits. Comparison of means showed that four critical traits that are seed yield, biological yield, harvest index, and oil yield were affected by experimental treatments. Different treatment conditions like drought stress, zeolite, and selenium application have a positive and significant effect on traits related to yield. In finally, zeolite and selenium application in drylands that are exposure to late-season drought stress can be helpful for yield improvement and prevention of decreasing yield.

Ahmed *et al.* (2008) conducted an experiment to study the effects of zeolite on soil nutrients and the growth of barley following irrigation with saline water. Barley was raised on a sand dune soil treated with calcium type zeolite at the rate of 1 and 5% and irrigated every alternate day with seawater diluted to 3 and 16 dS m^{-1} level of electrical conductivity (EC). However, a substantial improvement in plant biomass of salt-stressed barley was observed in zeolite-amended treatments. The application of zeolite also enhanced the water and salt holding capacity of the soil. Postharvest soil analysis exhibited high concentrations of calcium (Ca_2^+), magnesium (Mg_2^+), sodium (Na^+), and potassium (K^+) due to saline water especially in the upper soil layer but concentrations were lower in zeolite treated soils. Zeolite application at 5% increased Ca_2^+ concentration in salt-stressed plants; concentrations of trace elements were also increased by 19% for iron (Fe_2^+) and 10% for manganese (Mn_2^+). The overall results indicated that soil amendment with zeolite could effectively ameliorate salinity stress and improve nutrient balance in sandy soil.

Effects of natural zeolite on growth and flowering of strawberry were studied by Abdi *et al.* (2006) and the experiment was conducted as a complete randomized design with 4 treatments (0, 1, 2, and 3 g zeolite/kg soil) and 5 replications. Zeolite application at the rate of 3 g per kg soil gave the highest leaf area (187.61 cm^2), specific leaf weight (0.28 mg/cm^2), yield (104.69 g), and chlorophyll content. An increased amount of zeolite also gave increased petiole length (29.62 cm), fresh weights of shoots (57.64 g), dry weights of shoots (18.17 g), fresh weights of roots (34.864 g), dry weights of roots (7.59 g), fruit weight of primary fruits (11.83 g) and secondary fruits (6.71 g) and the number of achenes in primary fruits (299) and secondary fruits (244.4) of strawberry. Application of natural zeolite increased the available nitrogen (0.14%), potassium (145%), phosphorus (19.7%), calcium (6.5%) and magnesium (0.92%) of the medium. Zeolite also boosted net photosynthetic rate, stomatal conductance, water use efficiency, mesophyll efficiency.

Kılıç and Kılıç (2006) evaluated Gördes zeolite deposit of Turkey for industrial uses and reported that many materials can be used as growing media, they are those which have desirable features, such as abundant nutrients, high water retention capacity, adequate aeration, and easy transportation and availability, to ensure optimum seedling growth. Among these, though the use of growing media such as turf, perlite, vermiculite, pumice, and cocopeat for seedling production are important substrates, zeolite is considered as a promising media for this purpose; hence, zeolite could be easily used in seedling production.

Lisa (2006) conducted an experiment to investigate the effects of zeolites on the growth of cucumber and tomato seedlings at SLU. Plants of each species were planted in a peat:sand (3:1, vol:vol) mixture with the addition of 0%, 5%; 10% or 20% (vol/vol) of ZeoPro. ZeoPro is a commercial product, based on natural zeolite minerals and is claimed to improve plant performance, utilize nutrients more efficiently and reduce nutrient leaching to the environment. In this study, the effect of ZeoPro on cucumber and tomato seedlings was evaluated when 5%, 10%, and 20% ZeoPro was mixed into the growth medium. ZeoPro added to the growth medium exposed some increase in growth. In cucumber the growth increased with the increasing amount of ZeoPro, generating the largest plants with 20% ZeoPro and the smallest in the control group without ZeoPro. Plants treated with zeolite showed better plant height (200 mm), leaf area (300 cm^2), leaf number (4), fresh weight (9-10 g), dry weight (0.7-0.8 g) than the control group. The growth rate is the same in the beginning, but at the end of the trial, the values for average fresh weight and dry weight is higher as well as the leaf area. In tomato, the largest plants were found in the 5% group closely followed by the 10% and 20% groups. The plants in the control group, grown without ZeoPro were smaller than the other groups. Plants grown with zeolite showed better plant height (110 mm), leaf area (150-200 cm^2), leaf number (6-7), fresh weight (5 g), dry weight than the control group.

Noori *et al.* (2006) studied the influences of natural zeolite (clinoptilolite) on salinity and the presence of harmful salts in soil on *Raphanus sativus* L. For this purpose, six soil treatments: (a) control, (b) NaCl, (c) Na_2SO_4, (d) natural zeolite, (e) natural zeolite + NaCl and (f) natural zeolite + Na_2SO_4 was used. Also, planted five seeds of radish in each pot in which that six treatments repeated 10times. By preserving 50 days in an equal condition, some parameters i,e; the number of the leaf (NL), total leaf area (TLA), total fresh weight (TFW), total dry weight (TDW), root fresh weight (RFW), root dry weight (RDW), air fresh weight (AFW), and air dry weight (ADW) were determined. The results indicated that soil quality and increase crop yield maybe improve by using clinoptilolite. Also, the final product in radish cultivation increased with the implementation of natural zeolite as well as retained the harmful salt to pass through the roots to the plants.

Ersin *et al.* (2004) reported that zeolites have been increasingly used in various application areas such as industry, agriculture, environmental protection, and even medicine. Although there are no certain figures on the total amount of these minerals in the world, some countries like Cuba, USA, Russia, Japan, Italy, South Africa, Hungary, and Bulgaria, have significant reserves and production potentials. According to reports of 2001, the total consumption of zeolites was 3.5 million tons of which 18% came from their natural resources and the rest from synthetics. More than 40 naturally occurring zeolites were listed by different research groups, and clinoptilolite, erionite, chabazite, heulandite, mordenite, stilbit, and philipsite are the most well-known. Clinoptilolite is most commonly used for agricultural applications since it has high absorption, cation exchange, catalysis, and dehydration capacities. Zeolites are, therefore, used as a promoter for better plant growth by enhancing the value of fertilizers; retaining valuable nitrogen, and improving the quality of resulting manures and sludge. They can also be used as a filter medium or a molecular sieve.

Reha´kov *et al.* (2004) studied the agricultural and agrochemical uses of natural zeolite of the clinoptilolite type from the Eastern Slovakia deposit. Under the current requirements of ecological agriculture, there are ample areas of use for a natural, inert, and non-toxic material such as the natural zeolite of the clinoptilolite type. The structure of natural clinoptilolite is ideal for ion exchange and sorption processes. Due to its structure and properties, this natural, non-toxic and inert material can be used as a slowly releasing carrier of fertilizer, as well as other agrochemically, pharmaceutically, and biochemically active compounds including disinfectants. Natural zeolite can also be used to improve the physical properties of soils and for the treatment of contaminated soils.

Butorac *et al*. (2002) investigated crop response to the application of special natural amendments based on zeolite tuff. The primary objective of this research was to test the fertilizing value of SNA based zeolite tuff, their influence upon yield and yield components of some important field crops as well as some soil chemical properties. The main issue addressed in this study is how to elevate crop yield by increasing nutrient availability rather than how to neutralize the soil. This investigation, carried on pseudogley of mesoelevations, show that this can be achieved by the application of special natural amendments (SNA) based on zeolite tuff, under the name Agrarvital (AV) in which clinoptilolite prevails. Treatments applied in this investigation were AV-1 (1.5 t/ha), AV-2 (3 t/ha), Quicklime (QL) rate-1 (3.4 t/ha), QL-2 (6.8 t/ha), mixture of soft litothamnian limestone and dolomite SLL+D (rate-1:6 t/ha; rate-2:12 t/ha. Fertilizing value of Agrarvital (AV) and lime materials (LM) was evaluated according to the yields achieved and some yield components of the crops grown. In winter wheat cultivar Marija, best results in number of spikes per m^2 (483), grain yield (7.76 t/ha) was obtained from the combined application of mineral fertilizers and Agrarvital (SNA based zeolite). In maize, hybrid Pioneer 3737 achieved grain yield (8.18 t/ha) better by applying full fertilization and a higher rate of AV. In soybean, cultivar Crusader highest number of seed per pod (5) was obtained by applying AV. In winter barley, cultivar Sladoran, better grain yield (3.78 t/ha), length of spike (5.6 cm), no. of spikelets in spike (21) was noticed in treatment containing AV. The results denote the good fertilizing effect of AV upon yields of winter wheat, maize, soybean, and winter barley, equal to or better than the effect of conventional lime material applied at certain times higher rates.

Junrungreang *et al.* (2002) studied the effect of zeolite and chemical fertilizer on the change of physical and chemical properties on Lat Ya soil series for sugarcane. The experiment was conducted in randomized complete block design with 9 treatments in

3 replications. The treatments were control, application of chemical fertilizer at the rate 312.5 and 625 kg ha^{-1}, zeolite at the rate 125 and 250 kg ha^{-1}, chemical fertilizer at the rate 312.5 kg ha^{-1} incorporated with zeolite at the rate 125 and 250 kg ha^{-1}, and chemical fertilizer at the rate 625 kg ha^{-1} incorporated with zeolite at the rate 125 and 250 kg ha^{-1}. Chemical properties of Lat ya series, sugarcane growth, and yield were significantly increased by adding zeolite incorporated with chemical fertilizer. The treatments also significantly affected the available nutrients content in the soil. The changing of available nitrogen, phosphorus, potassium, calcium and magnesium in the soil were in the range 0.06-0.14%, 5.7-18.7 mg kg^{-1}, 127-150 mg kg^{-1}, 4.9-6.6 cmol kg^{-1} and 0.72-0.96 cmol kg^{-1} respectively. The combination of high dosage of chemical fertilizer (650 kg/ha) and high dosage of zeolite (250 kg/ha) showed the highest of the height (235 cm), diameter (4.2 cm), and yield of sugarcane (90.14 t/ha) including gave the best profit income (424.9 Dollar/ha).

Burriesci *et al.* (1984) studied zeolites' effect on crop growth of *Prunus persica* and *Vitis vinifera*. The results implicitly suggest that the growth and yield of the crops of *Prunus persica* and *Vitis vinifera* were greatly enhanced by Synthetic zeolites (from hydrothermal synthesis of Lipari pumice) in a formulated product with normal fertilizers compared to control plants. Also, the raw material (pumice) used for zeolitization originated supplement of micronutrients (Fe, Mg, Ca, and Na ions), enhanced absorption and retention capacities for major nutrient ions (such as K^+ and NH_4^+ from the fertilizer), maintained the adequate water supply & helped the slow release of fertilizers.

Valente *et al. (*1982) have tested the application of Zeolites (N36) as a soil conditioner in tomato-growing, obtained by hydrothermal synthesis from Lipari pumice. More than 50% average yield of tomato produced by the addition of the zeolite (N36) compared to the control plant. Also, comparing with the raw pumice and a commercial 4-A zeolite, it can be suggested that the beneficial effect has to be ascribed to other factors such as the presence of Fe and K rather than the exchange properties of aluminosilicates in tomato-growing.

CHAPTER III

MATERIALS AND METHODS

CHAPTER III

MATERIALS AND METHODS

This chapter delineates the methodology that was used in the fulfillment of the experiment demonstrating materials used for the experiment, treatments, experimental design, production technology, intercultural operation, data collection procedure, and statistical Moreover, It includes a short description of the location of the experimental site, climatic condition, soil characteristics.

3.1. Experimental site

The experiment was conducted at the Horticulture farm, Sher-e-Bangla Agricultural University, Dhaka during the period from October 2018 – March 2019 to study the effect of Zeolite on the growth and yield of some tomato varieties.

3.2. Geographical Location

The location of the experimental site is 23074 N latitude and 90035 E longitude and at an elevation of 8.2 m from sea level (Anon, 1989) in the Agro-Ecological Zone of Madhupur Tract (AEZ 28).

3.3. Climatic condition

The experimental site was located in the subtropical monsoon climatic zone, where heavy rainfall, high temperature, high humidity and relatively long day occurs from April to September (Kharif season) and meager rainfall along with moderately low temperature, low humidity and short day period during the rest of the year (Rabi season). During Rabi season (October to March), prevailing Moderate low temperature and ample amount of sunshine suitable for tomato cultivation in Bangladesh.

3.4. Characteristics of soil

The experimental site was medium high land and was under Tejgoan Series with olive-gray topsoil and common fine to medium distinct dark yellowish brown mottles. Soil characteristics of the experimental field were analyzed by Soil Resources and Development Institute (SRDI), Dhaka. The soil was clay loam in texture having 0.84% organic matter content. Soil pH ranged from 6.0-6.6. The experimental area was facilitated with good drainage and irrigation system.

3.5. Experimental materials

Five tomato varieties namely Sweden 5, Apple Netherland, TM 0.02, Roma VF and BARI Tomato-2 (Ratan) were used as planting material. Seeds of these tomato varieties were collected from Advanced Seed Research and Biotech Centre (ASRBC), ACI Limited. Cal Zeolite was collected from Century Agro Limited, Dhaka.

3.6. Treatments of the experiment

The two factorial experiment was conducted to evaluate the influence of zeolite doses on growth and yield of some tomato varieties. Factors are follows:

Factor A: Tomato varieties

In the experiment, five tomato varieties were used. These were:

V_1 = Sweden 5
V_2 = Apple Netherland
V_3 = TM 0.02
V_4 = Roma -VF
V_5 = BARI Tomato-2 (Ratan)

Factor B:

Zeolite application:

In this experiment, zeolite was applied as three different treatments.

Treatment

T_0 = No Zeolite application (Control)

T_1 = 12.5 kg/ha

T_2 = 18.5 kg/ha

The treatment combinations were:

V_1T_0, V_1T_1, V_1T_2, V_2T_0, V_2T_1, V_2T_2, V_3T_0, V_3T_1, V_3T_2, V_4T_0, V_4T_1, V_4T_2, V_5T_0, V_5T_1, V_5T_2.

Zeolite was applied as basal dose as per different treatment.

3.7. Design and layout of the experiment

The two factorial experiment was laid out following a Randomized completely block design (RCBD) with three replications. There were 45 unit plots in the experiment. The size of each plot was 3 m × 1 m with a 0.5 m distance from the block to block. 60 × 40 cm^2 distance was maintained from plant to plant.

3.8. Production Methodology

3.8.1 Seedbed preparation and raising of seedlings

Tomato seedlings were raised in seed trays in the Sher-e-Bangla Agricultural University. The soil was well prepared and converted into loose friable and dried mass by spading. All weeds, dead roots, and stubbles were removed. The soil was mixed with 5 kg well rotten cow dung. Seeds were treated with Bavistin for 5 minutes before sowing. After showing seeds are covered with light soil. The seedlings emerged within 5 to 6 days after sowing. Weeding, mulching, and irrigation were provided as and when required. 25 days old seedlings were transplanted in the main field.

3.8.2 Land preparation

The experimental plot was well pulverized with a power tiller and left exposed to the sun for a week to kill soil-borne pathogens and soil inhabitant insects. Then the plot was prepared by several plowing, cross plowing followed by laddering and harrowing with power tiller to bring about to good tilth. The land was leveled, corners were shaped and the clods were broken into pieces. Weeds and other stubbles were removed carefully from the experimental plot and leveled properly. Then the area was divided into plots of 3m x 1m according to the experiment design.

3.8.3 Manure and fertilizers applications

The entire amount of well rotten cow dung (@10 ton/ha) and triple super phosphate (TSP) (@200 kg/ha) were applied during final land preparation as a basal dose. Half Urea and half murate of potash (MOP) were applied in the plot after three weeks of transplanting. The remaining urea and murate of potash (MOP) were applied after five weeks of transplanting.

Table 1. Manures and fertilizers doses and application method used in the study

Fertilizers/Manures	Recommended dose	Application
Cowdung	10 ton/ha	Basal dose
Urea	300 kg/ha	Top dressing in two split doses - 3 and 5 weeks of transplanting
TSP	200 kg/ha	Basal dose
MOP	220 kg/ha	Top dressing in two split doses - 3 and 5 weeks of transplanting

3.8.4 Transplanting of Seedlings

Vigorous and uniform seedlings of 25 days old were transplanted in the main field on November 2, 2018, in the afternoon. Light irrigation was given immediately after transplanting and then seedlings were watered regularly to make a sturdy relation between plant roots and soil to stand along.

3.9 Intercultural operations

After transplanting the seedlings, various intercultural operations were performed for better growth and development of the tomato seedlings which are as follows:

3.9.1. Gap filling

A few gap filling was done by healthy tomato seedlings of the same stock where initially planted seedlings slipped to survive.

3.9.2. Weeding

Weeding was done to keep the plots clean and avoid crop weed competition which ultimately ensured better growth and development. Weeding was done uniformly in all the plots after well establishment of tomato seedlings.

3.9.3. Irrigation

Irrigation was furnished throughout the growing period by garden pipe and watering cane. The first irrigation was given immediately after the seedling transplantation whereas others were applied when required depending upon the moisture condition of the soil.

3.9.4. Staking

When the plants were well established, staking was done to each plant using bamboo sticks with rope to retain the plants upright. A few days after staking, as the plants grew up, other cultural operations were then carried out.

3.9.5. Pesticide application

Ripcord 10 EC were applied @ 10 ml/L to protect plants against disease infestation. The insecticide was applied for 3times at 10 days interval.

3.10. Harvesting

Frequent tomato picking was done throughout the harvesting period based on the horticultural maturity of fruits to avoid over riping of fruits.

3.11 Collection of Data

Three plants were selected randomly from each plot for data collection. Plants of outer rows and extreme ends of middle rows were excluded to avoid border effect. Data have been collected based on the following parameters-

Growth related parameter

- Plant height (cm)
- No. of leaves per plant
- No. of branches per plant

Physiological Parameter

- SPAD value

Duration related parameter

- Days to first flowering
- Days to first fruit ripening

Yield related parameter

- No. of cluster per plant
- No. of flower per cluster
- No. of fruit per cluster
- No. of fruit per plant
- Fruit length (mm)
- Fruit diameter (mm)
- Single fruit weight (g)
- Yield per plant (kg)
- Yield per hectare (t)

3.11.1. Plant height

The height of each sample plant was estimated in cm from the base of the plant to the tip of the top canopy and mean was computed. Plant height was calibrated using a meter scale.

3.11.2. Number of leaves /plant

The number of leaves per plant was manually counted from randomly selected plants to observe plant growth rate. Each leaf was counted from base to tip of the plant maintaining certain day intervals. Their average was counted as an average number of leaves per plant.

3.11.3. Number of branches per plant

A total number of branches per plant was manually counted from randomly selected plants and the average was considered as an average number of branches per plant.

3.11.4. SPAD Value

SPAD value was assessed by using the portable chlorophyll meter (SPAD-502). Three mature leaves were selected randomly from each treatment. Data were taken from three portions of each leaf randomly. The average was calculated and expressed as SPAD value.

3.11.5 Days to first flowering

Each plot was observed regularly to record the date of first flowering. The period between the date of transplanting to the date of first flowering was recorded and expressed in terms of the number of days.

3.11.6 Days to first fruit maturity

Days to first fruit ripening were recorded from date of transplanting to the date of first fruit ripening for each treatment.

3.11.7 No. of cluster per plant

The number of clusters per plant was counted manually from randomly selected plants at certain days interval and the average was recorded.

3.11.8 No. of flower per cluster

The number of flower per cluster was manually counted from randomly selected plants at certain days interval. The average was calculated and expressed as average number of flower per cluster.

3.11.9 No. of fruit per cluster

From randomly selected plants, total fruit number in every cluster was counted manually

The average was computed and expressed as average number of fruit per cluster.

3.11.10 No. of fruit per plant

From randomly selected plants, number of fruit was counted and then the average was computed and expressed as the average number of fruit per plant.

3.11.11 Fruit length (mm)

Fruit length was measured using Digital Calipers-515 (DC-515) in millimeter (mm). Mean value was determined for each treatment.

3.11.12 Fruit diameter (mm)

Fruit diameter was measured using Digital Calipers-515 (DC-515) in millimeter (mm). Mean value was determined for each treatment.

3.11.13 Single fruit weight (g)

Single fruit weight was measured using Electronic Precision Balance in grams. Fruits collected from three randomly selected plants of each treatment plot were weighed. The average was computed as a single fruit weight.

3.11.14 Yield per plant (kg)

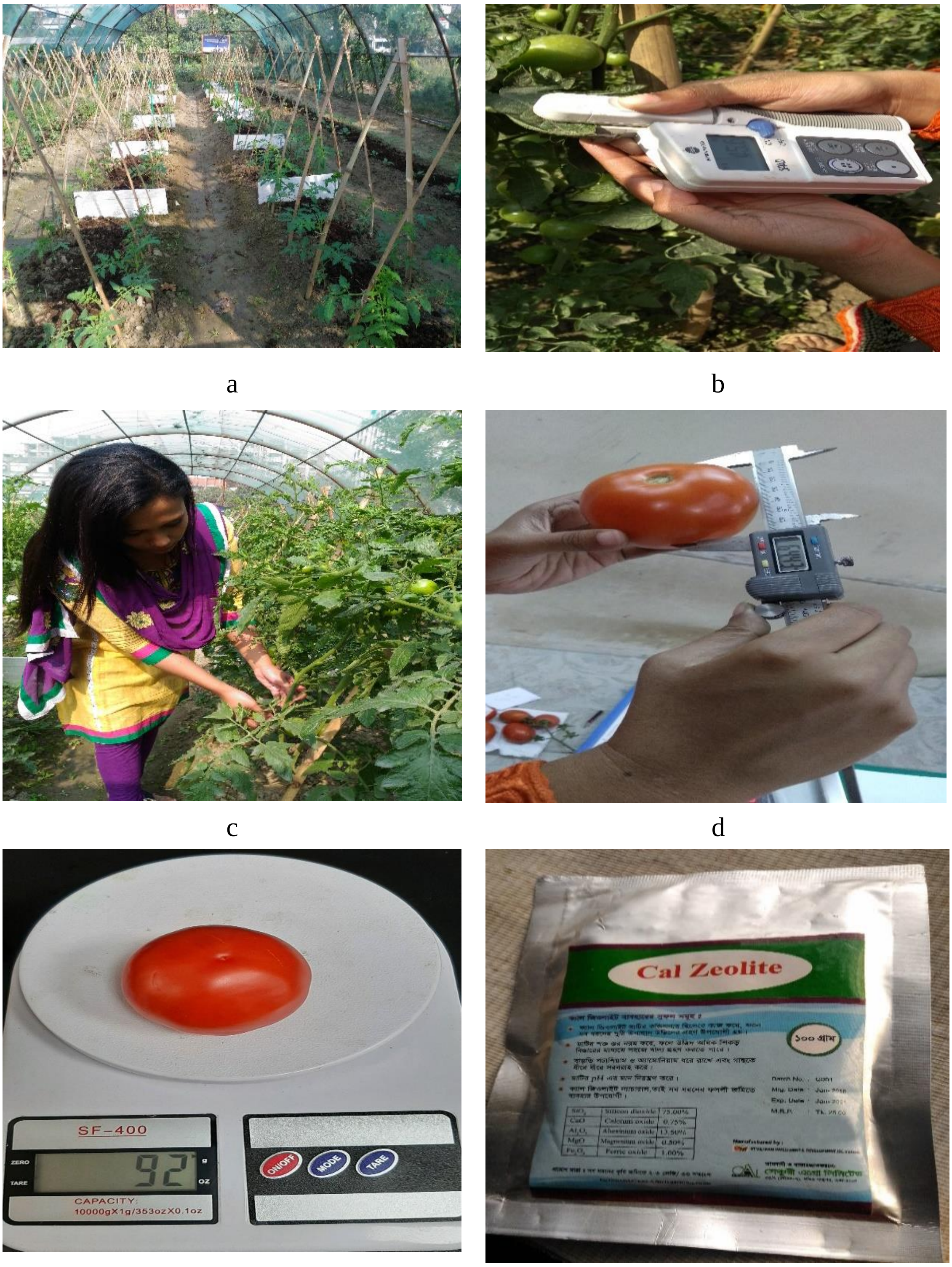
The total weight of fruits per selected plants were calculated using balance and expressed as yield per plant. It is expressed in kilogram (kg).

3.11.15 Yield per hectare (t)

Yield per hectare was calculated from the fruit yield obtained from each experimental plot and was expressed in tons per hectare.

3.12. Statistical analysis

The collected data for different parameters were statistically analyzed using the MSTAT-C computer package program to evaluate significant variation between different treatments. The mean values of all the recorded parameters were evaluated and analysis of variance for each of the parameters was performed by F–test (Variance Ratio). The difference between treatments was assessed by the Least Significant Difference (LSD) test at 0.05% level of significance (Gomez and Gomez, 1984).

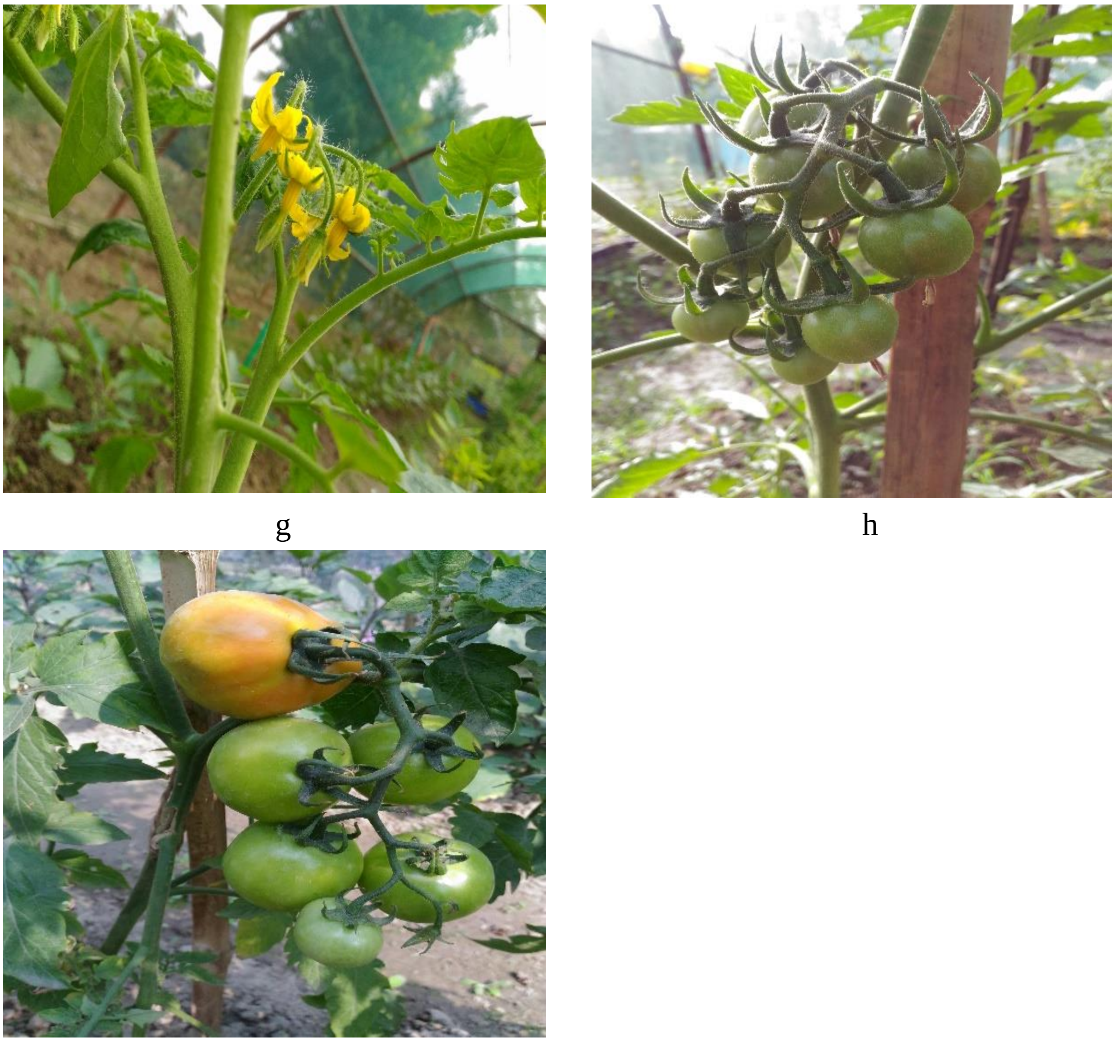


a b

c d

e f

Plate.1. Pictorial presentation of different methodological works. **a.** Staking of plant, **b.** Measurment of SPAD value, **c.** Collecting data, **d.** Measurement of fruit diameter using digital caliper-515 in millimeter (mm), **e.** Measurment of single fruit weight using electrical balance, f. Cal Zeolite used as treatment

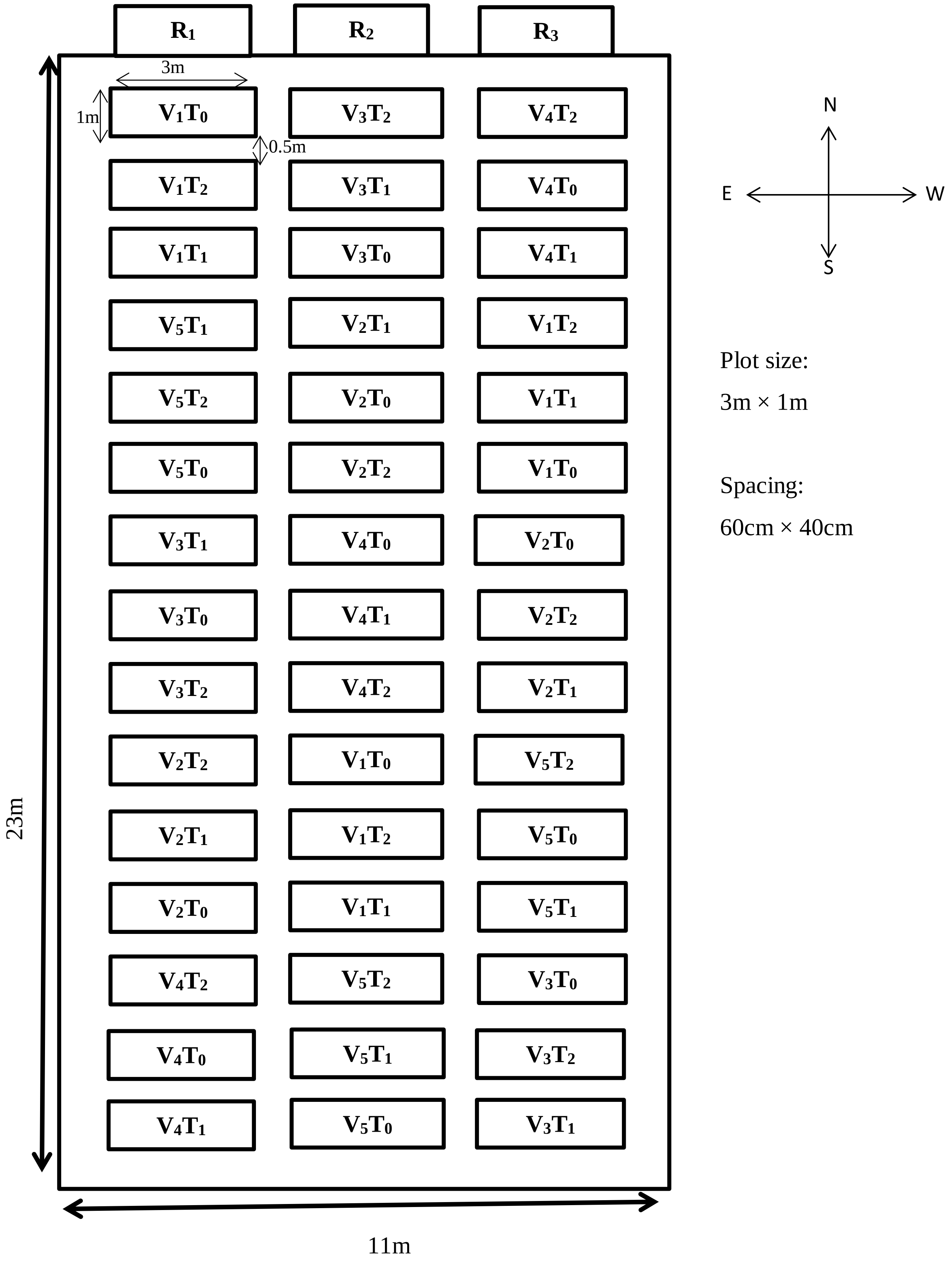


g

h

i

Plate.1. Pictorial presentation of different methodological works. **g.** Flower number per cluster, **h.** Fruit number per cluster, **i.** First fruit ripening.



Plot size:

3m × 1m

Spacing:

60cm × 40cm

Fig.1. Layout of the experiment

CHAPTER IV

RESULTS AND DISCUSSION

CHAPTER IV

RESULT AND DISCUSSION

The experimental trial was conducted to appraise the growth and yield performances of tomato varieties against zeolite application. The findings of the research work are presented, discussed, and evaluated in this chapter with necessary tables and figures under the following headings:

4.1 Plant height (cm)

Plant height is one of the most significant growth parameters which has a prominent influence on the yield performance and likewise has a positive correlation with the tomato yield. Significant variation was found among the tomato varieties performance in terms of plant height (Appendix I). Plant height was found to be significantly varied among different tomato varieties at 20days, 35days, 50days, 65days, and 80days after transplanting. The highest plant height was recorded in V_1 (138.8 cm), on the contrary, the lowest value was found in V_3 (97.2 cm) at 80 days after transplanting (Fig. 2).

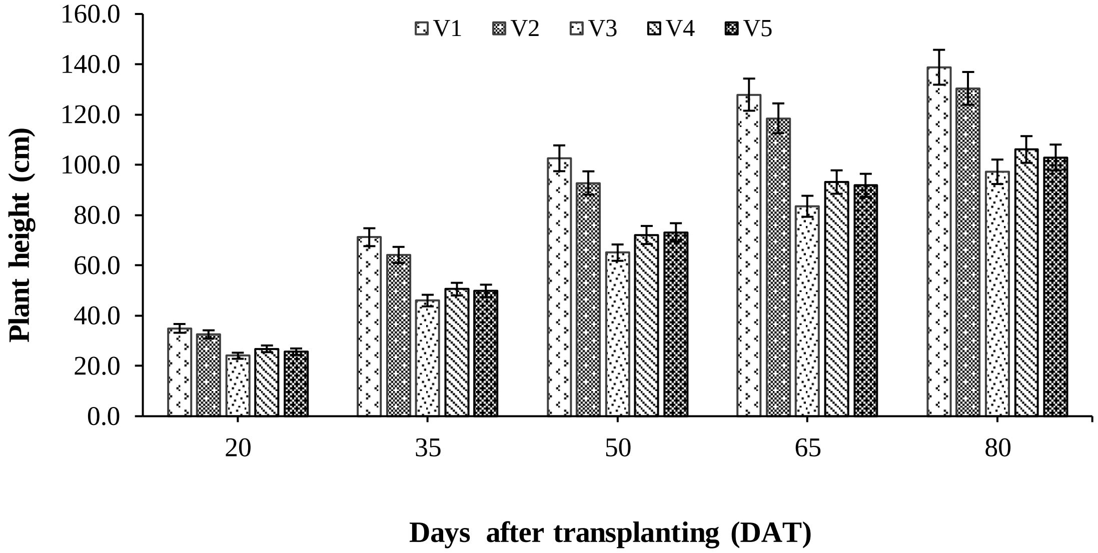


Fig. 2. Performance of different tomato varieties on plant height at different days after transplanting (V_1: Sweden 5; V_2: Apple Netherland; V_3 : TM 0.02 V_4: Roma VF and V_5: BARI Tomato-2)

A significant increase was observed from 20-65 DAT in all tomato varieties which then showed a slower rate at 65-80 DAT indicating reaching its maturity phase.

Plant height was significantly influenced by zeolite treatments (Appendix I) and exposed statistically significant in variation among T_0 (control), T_1 (12.5 kg/ha) and T_2 (18.5 kg/ha) (Fig. 3). Highest plant height (123.1 cm) was recorded for 18.5 kg zeolite applied per ha (T_2) and lowest was 106.6 cm for control condition (T_0) at 80 DAT. Tallest plants was found from T_2 treatment; i.e. 32.0 cm, 60.8 cm, 86.5 cm, 109.7 cm at 20, 35, 50, 65 DAT whereas minimum height was found from control (T_0) 25.3 cm, 51.7 cm, 75.3 cm, 96.2 cm at 20, 35, 50, 65 DAT respectively.

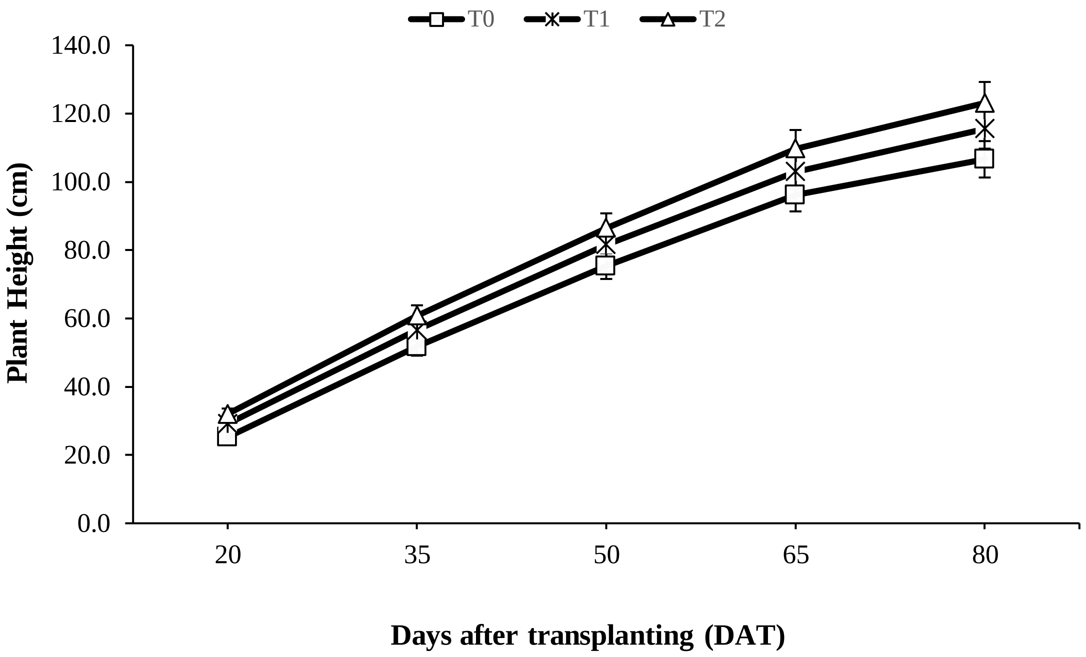


Fig. 3. Influence of zeolite doses on plant height (cm) at different days after transplanting of tomato (T_0: No zeolite application (control); T_1: 12.5 kg/ha; T_2: 18.5 kg/ha)

It seems that, zeolite improved soil cation exchangeable capacity and so water and nutrients were more accessible for tomato plants. Positive effect of zeolite on plant height can be related to increment of nutrient availability and prevention of nitrogen leaching.

A commercial product called ZeoPro, based on natural zeolite minerals and developed as a plant growth medium, was used and claimed to improve plant performance, utilize nutrients more efficient and reduce nutrient leaching to the environment (ZeoponiX, 2000).

Lisa (2007) stated that the high ion-exchange and retention ability of natural sedimentary zeolites (in particularly clinoptilolites) as wells as their large adsorptive affinity for water has contributed to their successful applications in plant growth.

In case of plant height, combined effect of tomato varieties and different zeolite treatments

exposed significant variation (Appendix I). Plant height exposed significant diversity among combination of tomato varieties and zeolite application at 20, 35, 50, 65, 80 DAT. Tallest plant (148.3 cm) was found in Sweden 5 (V_1) for T_2 (18.5 kg zeolite per ha) and shortest (90.5 cm) was obtained for control (T_0) in TM 0.02 (V_3) (Table 2). According to Gül *et al*. (2007), cucumbers grown in perlite + clinoptilolite substrate 3:1 were taller than other treatments. This may be due to the increase of soil fertility by zeolite by increasing the availability of nitrogen, potassium and phosphorus, as well as the role of zeolite in improving soil properties, increasing water retention, increasing the positive exchange capacity (CEC) of the soil and increasing the soil nutrient content, which increases the susceptibility of the plant to absorb nutrients (Ghazavi, 2015).

Table 2. Combined effect of tomato varieties and zeolite doses on plant height at different days after transplanting (DAT)

	Plant height (cm)				
Combination	20DAT	35DAT	50DAT	65DAT	80DAT
V_1T_0	31.2 cd	65.5 c	95.4 d	120.6 c	129.6 d
V_1T_1	35.4 b	71.4 b	103.8 b	127.7 b	138.4 b
V_1T_2	38.1 a	76.7 a	108.4 a	135.3 a	148.3 a
V_2T_0	28.3 e-g	58.5 d	86.5 e	109.6 d	120.4 e
V_2T_1	33.1 c	64.4 c	93.6 d	119.5 c	132.6 c
V_2T_2	36.3 ab	69.6 b	98.2 c	126.5 b	138.3 b
V_3T_0	20.7 k	41.5 i	60.5 k	78.5 j	90.5 k
V_3T_1	24.6 hi	46.8 gh	64.5 j	82.0 i	95.5 j
V_3T_2	26.9 fg	49.7 f	70.2 h	89.9 g	105.7 hi
V_4T_O	23.8 ij	47.5 g	66.6 ij	86.6 h	97.1 j
V_4T_1	26.4 f-h	49.6 f	72.7 g	92.2 g	107.8 gh
V_4T_2	30.2 de	54.5 e	77.0 f	100.6 e	113.4 f
V_5T_0	22.3 jk	45.3 h	67.5 i	85.5 h	95.6 j
V_5T_1	26.2 gh	50.7 f	73.4 g	93.6 f	103.6 i
V_5T_2	28.4 ef	53.4 e	78.4 f	96.4 e	109.6 g
CV%	4.29	2.14	1.60	1.25	1.28
LSD Value	2.07	2.02	2.17	2.15	2.47

Here, V_1: Sweden 5; V_2: Apple Netherland; V_3 : TM 0.02 V_4: Roma VF and V_5: BARI Tomato-2 and T_0: No zeolite application (control); T_1: 12.5 kg/ha; T_2: 18.5 kg/ha

In a column means having similar letter (s) are statistically identical and those having dissimilar letter (s) differ significantly as per 0.05 level of probability.

4.2 Leaf Number

Leaf number has a profound effect on plant productivity which is one of the principal plant organs. An ample quantity of leaves symbolizes more vigorous crop growth and development. The number of leaves was significantly varied in the case of tomato varieties (Appendix II). Leaf number exposed statistically significant difference among five tomato varieties (V_1, V_2, V_3, V_4, V_5) at 20, 35, 50, 65, and 80 days after transplanting (Fig. 4). The highest leaf number was found from V_1 (77.9) and the least number was exhibited in V_3 (65.5) at 80 DAT.

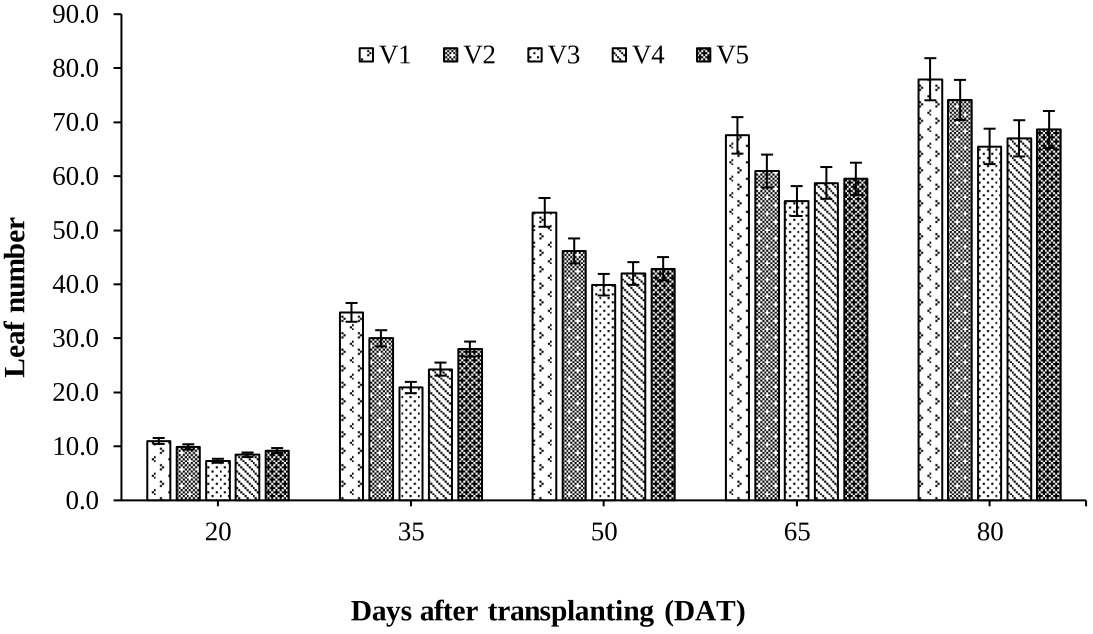


Fig. 4. Performance of different tomato varieties on leaf number at different days after transplanting (V_1: Sweden 5; V_2: Apple Netherland; V_3: TM 0.02 V_4: Roma VF and V_5: BARI Tomato-2)

Different zeolite doses significantly affected the leaf number of tomato plants (Appendix II). Maximum leaf number was counted in T_2 (73.5) treatment at 80 days and the minimum was counted from T_0 (68.0) at 80 DAT (Fig. 5). The data by Markovic *et al.* (2000) showed that peppers of better quality were grown in peat (2/3) and zeolite (1/3) substrates. They were taller and had more leaves than other treatments.

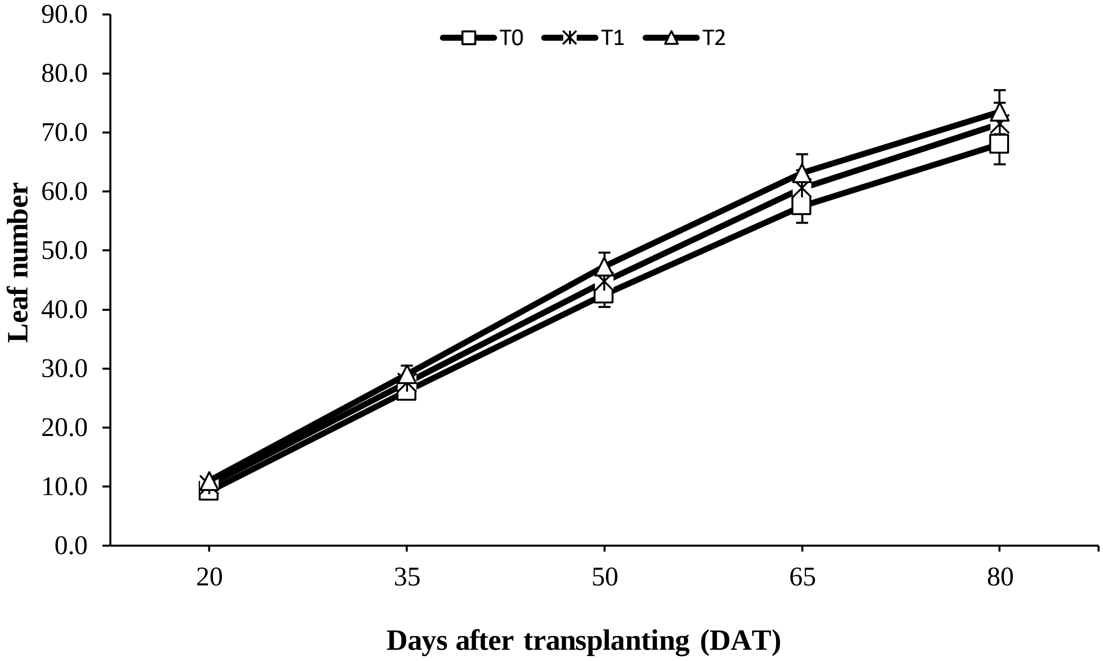


Fig. 5. Influence of zeolite doses on leaf number at different days after transplanting of tomato (T_0: No zeolite application (control); T_1: 12.5 kg/ha; T_2: 18.5 kg/ha)

Application of zeolite in the soil improve nutrient and water availability to plant root which helps to increase the absorption of nutrients and water that contribute to the growth and elongation of cells and stimulate cell division and expansion and perhaps the increase number of leaves (Nisreen *et al.*, 2020).

Tomato leaf number also displayed significant variation in response to the combined effect of different tomato varieties and zeolite application (Appendix II). Leaf number of different tomato varieties had revealed statistically significant variation among treatments at 20, 35, 50, 65 and 80 DAT (Table 3). In combination, the highest leaf number (81.7) was found in Sweden 5 (V_1) with T_2 While the lowest value (63.0) was found with control (T_0) in TM 0.02 (V_3).

Table 3. Combined effect of varieties and zeolite doses on number of leaves per plant at different days after transplanting (DAT) of tomato

	Leaf number				
Combination	20DAT	35DAT	50DAT	65DAT	80DAT
V_1T_0	10.0 bc	32.3 c	50.7 c	64.7 c	74.0 cd
V_1T_1	11.0 ab	35.0 b	53.3 b	67.3 b	78.3 b
V_1T_2	12.0 a	37.7 a	56.7 a	71.0 a	81.7 a
V_2T_0	9.0 c-f	29.0 ef	44.0 e	58.3 h	71.0 de
V_2T_1	9.7 b-d	30.0 de	46.3 d	61.3 ef	74.3 cd
V_2T_2	11.0 ab	31.7 cd	48.3 d	63.7 cd	77.3 bc
V_3T_0	6.3 g	19.3 l	38.0 h	53.0 k	63.0 h
V_3T_1	7.7 e-g	21.0 kl	40.3 fg	56.7 j	65.3 gh
V_3T_2	8.0 d-g	22.3 jk	41.7 fg	57.7 hi	68.3 efg
V_4T_O	7.3 fg	23.3 j	40.7 g	56.0 ij	65.7 gh
V_4T_1	9.0 c-f	24.0 ij	42.0 f	58.7 gh	66.7 fg
V_4T_2	9.0 c-f	25.7 hi	44.3 e	61.3 ef	69.3 ef
V_5T_0	8.3 c-f	27.0 gh	40.0 fg	56.3 ij	65.7 gh
V_5T_1	9.3 b-e	28.0 fg	42.0 f	60.0 fg	69.0 ef
V_5T_2	10.0 bc	29.0 ef	46.3 d	62.3 de	71.3 de
CV%	6.66	4.50	2.59	1.56	2.77
LSD Value	1.79	1.78	1.9	1.52	3.28

Here, V_1: Sweden 5; V_2: Apple Netherland; V_3 : TM 0.02 V_4: Roma VF and V_5: BARI Tomato-2 and T_0: No zeolite application (control); T_1: 12.5 kg/ha; T_2: 18.5 kg/ha

In a column means having similar letter (s) are statistically identical and those having dissimilar letter (s) differ significantly as per 0.05 level of probability.

4.3. Number of branches per plant

The number of branches per plant exhibited significant inequality among five tomato varieties (V_1, V_2, V_3, V_4, and V_5) at 20, 35, 50, 65, and 80 days after transplanting (Appendix III). Highest number of branches was showed in V_5 (8.3) at 80 days after transplanting and least number of branches was found in V_3 (5.0) at 80 days after transplanting (Table 4).

Branch number statistically varied in terms of zeolite application (Appendix III). A maximum number of branches (7.3) was found at T_2 and minimum number of branches (5.7) was found in the case of control (T_0) (Table 5). Zeolite application has a beneficial effect on the branch number of plants. These differences may be attributed to the fact that by improving nutrient and water use efficiency, zeolite helps to provide available nutrients at the critical stages of the development which exerts a positive effect in development of branches. Ramesh *et al.* (2015) reported that additions of fly ash zeolites to soil at 2% level was found to benefit number of branches in sweet potato plants.

In case of combination treatment, significant variation was observed in branch number (Appendix III). Highest number of branches was found in V_5T_2 (9.3) and lowest number of branches was found in V_3T_0 (4.3) (Table 6).

4.4. SPAD value

SPAD value displayed significant variation among five tomato varieties V_1, V_2, V_3, V_4, and V_5 (Appendix III). Highest value (46.0) was observed in V_2 (Apple Netherland) and lowest value (30.8) was found in V_5 (BARI Tomato-2). V_1 (Sweden 5) had a SPAD value of 37.2 which is statistically similar to V_3 (37.6) and V_4 (37.2) (Table 4).

In case of zeolite application, SPAD value of tomato leaves showed significant variation (Appendix III). Maximum SPAD value (40.2) was found in T_2 level of treatment, while the lowest value (35.3) was observed in T_0 (control) (Table 5), which was due to availability of different elements and water for plants by using zeolite.

The incorporation of zeolite into substrate has a positive effect on photosynthesis parameters, pigment content in plant leaves, root growth and mass (Abdi *et al*. 2006). Kaszab (2008) stated that a higher photosynthesis rate can also lead to favorable effects on plant productivity, including an increase in yield and fruit size. Krutilina *et al.* (2000) indicated that zeolite increased biomass production and photosynthetic rate in maize and barley.

Combination treatment of five tomato varieties and zeolite had significant variation on SPAD value (Appendix III). SPAD value of five tomato varieties showed significant difference among T_0, T_1 and T_2. Highest SPAD value was observed for V_2T_2 (48.3) which is statistically similar to V_2T_1 (46.4) and the lowest SPAD value was found in V_5T_0 (28.3) which is statistically similar with V_5T_1 (30.2) (Table 6).

4.5. Days to 1st flowering

Significant variation was observed among the tomato varieties in respect of days to flowering after transplantation (Appendix III). Longest period was required in V_3 (42.9 days) for flowering while shortest period was in V_4 (40.0 days) (Table 4).

Significant dissimilarity was observed in days to first flowering due to different zeolite treatments (Appendix III). Earliest flowering (39.5 days) was observed in T_2 treatment while late flowering (41.4 days) was in T_0 Treatment (Table 5).

Combination of different varieties and zeolite treatment at different levels influenced on days taken to flowering (Appendix III). V_4T_2 (39.0) required minimum period for flowering whereas maximum from V_3T_0 (43.9) (Table 6).

Table 4. Performance of five tomato varieties on number of branches/plant, SPAD value, days to 1st flowering, days to 1st fruit maturity

Variety	Number of branches/plant	SPAD value	Days to 1st flowering	Days to 1st fruit maturity
V_1	7.6 b	37.2 b	41.4 bc	73.1 bc
V_2	6.2 c	46.0 a	40.8 cd	72.9 c
V_3	5.0 e	37.6 b	42.9 a	75.3 a
V_4	5.6 d	37.2 b	40.0 d	71.4 d
V_5	8.3 a	30.8 c	42.0 b	73.9 bc
CV%	6.68	3.65	2.30	1.45
LSD	0.42	1.33	0.92	0.93

Here, V_1: Sweden 5; V_2: Apple Netherland; V_3 : TM 0.02 V_4: Roma VF and V_5: BARI Tomato-2 and T_0: No zeolite application (control); T_1: 12.5 kg/ha; T_2: 18.5 kg/ha

In a column means having similar letter (s) are statistically identical and those having dissimilar letter (s) differ significantly as per 0.05 level of probability.

Table 5. Influence of zeolite doses on number of branches/plant, SPAD value, days to 1st flowering, days to 1st fruit maturity

Zeolite doses	Number of branches/plant	SPAD value	Days to 1st flowering	Days to 1st fruit maturity
T_0	5.7 c	35.3 c	41.4 a	75.3 a
T_1	6.6 b	37.8 b	40.3 b	73.1 b
T_2	7.3 a	40.2 a	39.5 c	71.4 c
CV	6.68	3.65	2.30	1.45
LSD	0.33	1.03	0.71	0.72

Here, V_1: Sweden 5; V_2: Apple Netherland; V_3 : TM 0.02 V_4: Roma VF and V_5: BARI Tomato-2 and T_0: No zeolite application (control); T_1: 12.5 kg/ha; T_2: 18.5 kg/ha

In a column means having similar letter (s) are statistically identical and those having dissimilar letter (s) differ significantly as per 0.05 level of probability.

4.6. Days to 1st fruit maturity

Significant variation was found among five tomato varieties V_1, V_2, V_3, V_4, and V_5 in terms of days to first fruit maturity after transplantation of seedling (Appendix III). Longest period was required in V_3 (75.3) and shortest period in V_4 (71.4) for fruit maturity (Table 4).

Significant dissimilarity was observed in terms of days to first fruit maturity due to different zeolite treatments (Appendix III). Longest period was required in T_0 (75.3) and shortest period in T_2 (71.4) for fruit maturity (Table 5).

Combination of five tomato varieties and zeolite at different levels influenced significantly the number of days taken to first fruit maturity (Appendix III). Earliest fruit maturity was observed in V_4T_2 (69.3) and delayed fruit maturity was observed in V_3T_0 (77.7) (Table 6). Hatwar *et al.* (2003) observed that this might be due to the increase of photosynthesis, deposition of photo assimilates, translocation of carbohydrates, improvement in physiological and other metabolic activity which led to a rise in various plant metabolites responsible for actively cell division and elongation resulting improvement in growth characteristics.

Table 6. Combined effect of tomato varieties and zeolite doses on number of branches/plant, SPAD value, days to 1st flowering, days to 1st fruit maturity

Combination	Number of branches/plant	SPAD value	Days to 1st flowering	Days to 1st fruit maturity
V_1T_0	6.7 de	34.5 g	42.7 ab	75.0 bc
V_1T_1	7.7 bc	37.1 ef	41.0 cd	73.3 d-f
V_1T_2	8.3 b	40.0 c	40.7 cd	71 .0 g
V_2T_0	5.3 gh	43.3 b	41.7 bc	74.3 b-d
V_2T_1	6.3 ef	46.4 a	40.7 cd	72.0 fg
V_2T_2	7.0 c-e	48.3 a	40.0 de	72.3 g
V_3T_0	4.3 i	35.7 fg	43.9 a	77.7 a
V_3T_1	5.0 g-i	37.6 d-f	43.0 ab	75.3 b
V_3T_2	5.7 fg	39.6 cd	42.0 bc	73.0 d-f
V_4T_O	4.7 hi	34.5 g	41.0 cd	74.0 d-f
V_4T_1	5.7 fg	37.8 c-f	40.0 de	71.0 g
V_4T_2	6.3 ef	39.2 c-e	39.0 e	69.3 h
V_5T_0	7.3 cd	28.3 h	43.0 ab	75.7 b
V_5T_1	8.3 b	30.2 h	42.0 bc	73.7 c-e
V_5T_2	9.3 a	34.0 g	41.0 cd	72.3 e-g
CV%	6.68	3.65	2.30	1.45
LSD	0.73	2.306	1.594	1.61

Here, V_1: Sweden 5; V_2: Apple Netherland; V_3 : TM 0.02 V_4: Roma VF and V_5: BARI Tomato-2 and T_0: No zeolite application (control); T_1: 12.5 kg/ha; T_2: 18.5 kg/ha

In a column means having similar letter (s) are statistically identical and those having dissimilar letter (s) differ significantly as per 0.05 level of probability.

4.7. Number of cluster per plant

Significant variation was recorded among five tomato varieties in terms of number of cluster per plant (Appendix IV). Maximum number of cluster was found in V_1 (7.5) at 80 days after transplanting and minimum number of cluster was found in V_4 (5.8) (Table 7).

Zeolite application displayed statistically significant variation in number of cluster per plant (Appendix IV). Maximum number of cluster per plant was recorded in T_2 (7.2) treatment at 80 DAT whereas minimum cluster number was found in control at T_0 (6.1) at 80 DAT (Table 8).

The high affinity of zeolite for plant nutrients especially $NH4^+$ have made it to be used to improve soil nitrogen retention and nitrogen availability to plants. Zeolites have been reported to improve N use efficiency and increase yield of many crops such as spinach (Li *et al.,* 2013), canola (Bybordi and Ebrahimian, 2013), corn (Bernardi *et al.,* 2011) and rice (Sepaskhah and Barzegar, 2010) (Kavoosi, 2007).

Combined effect of tomato varieties and zeolite application significantly influenced the production of number of cluster per plant (Appendix IV). Highest number of cluster was found from V_1T_2 (8.0) combination and minimum was found from V_4T_0 (5.3) at 80 days after transplanting of tomato varieties (Table 9).

4.8. Number of flower per cluster

Floral induction is a key developmental switch in crop plants that leads to the production of flowers, fruits and seeds to meet the demands of harvest per year. The flower number is crucial indication of the ultimate yield for any crop plant. Flower number per cluster displayed significant variation among five tomato varieties V_1, V_2, V_3, V_4, and V_5 (Appendix IV). Highest value (9.6) was observed in V_1 (Sweden 5) and lowest value (7.8) was found in V_5 (BARI Tomato-2) (Table 7). Hancock, (1999) reported that the number of strawberry flowers are related to number and diameter of crowns, which can be used to predicted plant yield potential.

In case of zeolite application, Flower number per cluster varied significantly (Appendix III). Maximum number of flower per cluster (9.3) was found in T_2 level of treatment, while minimum number of flower (8.1) was observed in T_0 (control) (Table 8).

Flower number per cluster exposed significant dissimilarities among the combination of different tomato varieties and zeolite application at different levels (Appendix IV). Maximum number of flower per cluster was found in V_1T_2 (10.1) level of treatment, while minimum number of flower (7.1) was observed in V_5T_0 (control) (Table 9). Patil *et al.* (2009) observed that the difference in flower number is due to the increasing number of branches and photosynthetic activity of plant. Harb and Mahmoud (2009) found that with zeolite added to soil, plant fresh and dry mass as well as chlorophyll content in plants increase.

4.9. Number of fruit per cluster

The number of fruit per cluster exhibited significant inequality among five tomato varieties (V_1, V_2, V_3, V_4, and V_5) (Appendix IV). Highest number of fruit per cluster was showed in V_1 (7.4) at 80 days after transplanting and least number of fruits per cluster was found in V_5 (5.6) at 80 days after transplanting (Table 7).

Fruit number per cluster statistically varied in terms of zeolite application (Appendix IV). A maximum number of fruit per cluster (6.9) was found at T_2 and minimum number of fruit per cluster (5.8) was found in the case of control (T_0) (Table 8). Zeolite application displayed a beneficial effect on per cluster fruit number of tomato plants. This result may due to zeolite helped to better the nutrient use efficiency by plants. According to Leggo (2000) zeolites may be used in growth media to improve plant yields. Mixtures of zeolite and fertilizers also had positive effects on tomato (Ashraf, 2011) and cucumber (Bozorgi *et al.* 2012) yields.

Table 7. Performance of five tomato varieties on number of cluster/plant, number of flower/cluster, number of fruit /cluster, number of fruit/plant

Variety	No of cluster/plant	No of flower/cluster	No. of fruit/cluster	No. of fruit/plant
V_1	7.5 a	9.6 a	7.4 a	42.1 a
V_2	6.3 c	9.2 ab	6.2 bc	36.1 d
V_3	6.7 bc	8.7 b	6.1 c	37.3 c
V_4	5.8 d	8.7 b	6.7 b	38.8 b
V_5	6.8 b	7.8 c	5.6 d	35.3 d
CV%	5.82	6.59	5.77	3.08
LSD	0.37	0.56	0.36	1.13

Here, V_1: Sweden 5; V_2: Apple Netherland; V_3 : TM 0.02 V_4: Roma VF and V_5: BARI Tomato-2 and T_0: No zeolite application (control); T_1: 12.5 kg/ha; T_2: 18.5 kg/ha

In a column means having similar letter (s) are statistically identical and those having dissimilar letter (s) differ significantly as per 0.05 level of probability.

Table 8. Influence of zeolite doses on number of cluster/plant, number of flower/cluster, number of fruit /cluster, number of fruit/plant

Zeolite doses	No of cluster/plant	No of flower/cluster	No. of fruit/cluster	No. of fruit/plant
T_0	6.1 c	8.1 c	5.8 c	36.0 c
T_1	6.6 b	8.9 b	6.4 b	38.2 b
T_2	7.2 a	9.3 a	6.9 a	39.6 a
CV%	5.82	6.59	5.77	3.08
LSD	0.33	0.42	0.26	0.87

Here, V_1: Sweden 5; V_2: Apple Netherland; V_3 : TM 0.02 V_4: Roma VF and V_5: BARI Tomato-2 and T_0: No zeolite application (control); T_1: 12.5 kg/ha; T_2: 18.5 kg/ha

In a column means having similar letter (s) are statistically identical and those having dissimilar letter (s) differ significantly as per 0.05 level of probability.

In case of combination treatment, significant variation was observed in fruit number per cluster (Appendix IV). Number of fruit per cluster of five tomato varieties exhibited significant inequality among different zeolite treatments. Highest number of fruit per cluster was found in V_1T_2 (8.0) and lowest number of fruit per cluster was found in V_5T_0 (5.0) (Table 9).

4.10. Number of fruit per plant

Significant variation was found among the tomato varieties performance in terms of number of fruit per plant (Appendix IV). The highest number of fruit per plant was recorded in V_1 (42.1), on the contrary, the lowest value was found in V_5 (35.3) which is statistically similar with V_2 (36.1) at 80 days after transplanting (Table 7).

Fruit number per plant was significantly affected by application of zeolite in tomato (Appendix IV). Fruit number of tomato plant exposed significant inequality among T_0, T_1, and T_2 treatment. Maximum number of fruits per plant was recorded in T_2 (39.6) and minimum was recorded in T_0 (36.0) (Table 8).

Polat *et al*. (2004) report that the mineral clinoptilolite (zeolite) enhances the efficacy of applied fertilizers, ensuring better vegetative growth of crops and hence higher yields. Clinoptililite-zeolite can easily absorb NH_4^+ and K^+ (Mumpton, 1999). Ebrahim *et al.* (2011) reported number of pod per plant with 40.2 pods was obtained by increasing zeolite application. Inclusion of zeolites in fertilizers management for agriculture is essential as besides serving as soil conditioner (including soil fertility improvement), zeolites have the potential to increase crop yield (Valente *et al*., 1982; Noori *et al*., 2006).

Fruit number per plant exposed significant dissimilarities among the combination of different tomato varieties and zeolite application at different levels (Appendix IV). Maximum number of fruit per plant was found in V_1T_2 (43.7) level of treatment, while minimum number of fruit (33.3) was observed in V_5T_0 (control) (Table 9).

Table 9. Combined effect of varieties and zeolite doses on number of cluster/plant, number of flower/cluster, number of fruit /cluster, number of fruit/plant

Combination	No of cluster/plant	No of flower/cluster	No. of fruit/cluster	No. of fruit/plant
V_1T_0	7.0 b-d	9.0 b-d	7.0 bc	40.3 b
V_1T_1	7.6 ab	9.7 ab	7.3 b	42.3 a
V_1T_2	8.0 a	10.1 a	8.0 a	43.7 a
V_2T_0	6.0 e-g	8.7 c-e	5.7 f-h	34.3 fg
V_2T_1	6.3 d-f	9.3 bc	6.2 d-f	36.7 c-e
V_2T_2	6.7 c-e	9.7 ab	6.7 b-d	37.3 c
V_3T_0	6.0 e-g	8.1 d-f	5.6 g-i	35.0 e-g
V_3T_1	6.7 c-e	8.7 c-e	6.1 e-g	37.3 c
V_3T_2	7.3 a-c	9.3 bc	6.7 b-d	39.7 b
V_4T_O	5.3 gh	8.0 e-g	6.2 d-f	37.0 cd
V_4T_1	5.7 f-h	8.7 c-e	6.7 c-e	39.3 b
V_4T_2	6.3 d-f	9.3 bc	7.1 bc	40.0 b
V_5T_0	6.0 e-g	7.1 gh	5.0 ij	33.3 g
V_5T_1	6.7 c-e	7.9 e-h	5.7 f-h	35.3 d-f
V_5T_2	7.7 ab	8.3 de	6.11 e-g	37.3 c
CV%	5.82	6.59	5.77	3.08
LSD	0.74	0.93	0.59	1.96

Here, V_1: Sweden 5; V_2: Apple Netherland; V_3 : TM 0.02 V_4: Roma VF and V_5: BARI Tomato-2 and T_0: No zeolite application (control); T_1: 12.5 kg/ha; T_2: 18.5 kg/ha

In a column means having similar letter (s) are statistically identical and those having dissimilar letter (s) differ significantly as per 0.05 level of probability.

4.11. Fruit length

Significant variation was recorded among five tomato varieties in terms of fruit length (Appendix V). Maximum fruit length was found in V_2 (54.6 mm) which is statistically similar with V_3 (53.9 mm) and minimum fruit length was found in V_5 (46.7 mm) (Table 10).

Zeolite application displayed statistically significant variation in respect of fruit length (Appendix V). Maximum number of cluster per plant was recorded in T_2 (54.3 mm) treatment at 80 DAT whereas minimum cluster number was found in control at T_0 (47.8 mm) at 80 DAT (Table 11). These differences may be due to the role of natural zeolite in providing better nutrient availability necessary for the growth and development of plants, especially nitrogen, phosphorus and potassium, which have a positive role in increasing vegetative growth as well as crop quality and productivity.

Combined effect of tomato varieties and zeolite application significantly influenced fruit length (Appendix V). Highest fruit length was found from V_2T_2 (57.7 mm) combination and minimum was found from V_5T_0 (43.2 mm) (Table 12).

4.12. Fruit Diameter

Significant variation was observed among the tomato varieties in respect of days to fruit diameter (Appendix V). Maximum fruit diameter was recorded from V_2 (59.0 mm) while shortest was in V_4 (40.7 mm) (Table 10).

Significant dissimilarity was observed in case of fruit diameter due to different zeolite treatments (Appendix V). Widest fruit (52.0 mm) was observed in T_2 treatment while least wide fruit (45.8 mm) was in T_0 Treatment (Table 11).

Combined effect of different varieties and Zeolite application in terms of fruit diameter exposed significant variation (Appendix V). V_2T_2 (61.9 mm) was recorded as widest whereas V_4T_0 (37.5 mm) was recorded as lowest (Table 12).
In a greenhouse experiment with radishes, the addition of ammonium-exchanged clinoptilolite resulted in increased root weight. The nitrogen uptake by the plant tops

also increased with the zeolite treatment compared with an ammonium sulphate control (Mumpton, 1985).

4.13. Single fruit weight

Single fruit weight displayed significant variation among five tomato varieties V_1, V_2, V_3, V_4, and V_5 (Appendix V). Highest value (93.2 g) was observed in V_2 (Apple Netherland) and lowest value (70.9 g) was found in V_4 (Roma VF) (Table 10).

In case of zeolite application, Single fruit weight varied significantly (Appendix V). Maximum fruit weight (84.8 g) was found in T_2 level of treatment, while minimum fruit weight (79.6 g) was observed in T_0 (control) (Table 11).

Zeolite improves nutrient and water use efficiency by adsorbing nutrient and water molecules in the void spaces of its structure and then slowly releases it to plant root. The nitrogen provided by zeolite plays a key role in increasing the weight of the seeds by entering the formation of the enzymes responsible for the biological processes in the plant such as photosynthesis (Barker and Pilbeam, 2007),

Single fruit weight exposed significant dissimilarities among the combination of different tomato varieties and zeolite application at different levels (Appendix V). Maximum fruit weight was found in V_2T_2 (96.6 g) level of treatment, while minimum fruit weight (68.6 g) was observed in V_4T_0 (Table 12). Lewis *et al.* (1984) observed that the addition of ammonium exchanged clinoptilolite zeolite in greenhouse experiment with radishes resulted in a 59 and 53 percent increase in root weight in medium and light clay soils, respectively.

Table 10. Performance of different tomato varieties on fruit length, fruit diameter, single fruit weight, yield/plant, yield/hectare

Variety	Fruit length (mm)	Fruit diameter (mm)	Single fruit weight (g)	Yield / plant (kg)	Yield /hectare(t)
V_1	48.5 c	51.8 b	87.0 b	3.3 a	93.1 a
V_2	54.6 a	59.0 a	93.2 a	3.1 b	90.8 b
V_3	53.9 a	42.3 d	73.4 c	2.6 d	80.3 e
V_4	52.4 b	40.7 e	70.9 d	2.7 cd	82.9 d
V_5	46.7 d	50.5 c	86.6 b	2.8 c	84.2 c
CV%	2.40	2.49	1.30	5.30	1.07
LSD	1.19	1.18	1.04	0.16	0.89

Here, V_1: Sweden 5; V_2: Apple Netherland; V_3 : TM 0.02 V_4: Roma VF and V_5: BARI Tomato-2 and T_0: No zeolite application (control); T_1: 12.5 kg/ha; T_2: 18.5 kg/ha

In a column means having similar letter (s) are statistically identical and those having dissimilar letter (s) differ significantly as per 0.05 level of probability.

Table 11. Influence of zeolite doses on fruit length, fruit diameter, single fruit weight, yield/plant, yield /hectare

Zeolite doses	Fruit length (mm)	Fruit diameter (mm)	Single fruit weight (g)	Yield / plant (kg)	Yield /hectare(t)
T_0	47.8 c	45.8 c	79.6 c	2.8 c	83.5 c
T_1	51.5 b	48.7 b	82.3 b	2.9 b	86.5 b
T_2	54.3 a	52.0 a	84.8 a	3.1 a	88.8 a
CV%	2.40	2.49	1.30	5.30	1.07
LSD	0.92	0.91	0.8	0.12	0.69

Here, V_1: Sweden 5; V_2: Apple Netherland; V_3 : TM 0.02 V_4: Roma VF and V_5: BARI Tomato-2 and T_0: No zeolite application (control); T_1: 12.5 kg/ha; T_2: 18.5 kg/ha

In a column means having similar letter (s) are statistically identical and those having dissimilar letter (s) differ significantly as per 0.05 level of probability.

4.14. Yield per plant

Significant variation was found among five tomato varieties V_1, V_2, V_3, V_4, and V_5 in terms of yield per plant (Appendix V). Highest yield per plant was found in V_1 (3.3 kg) and lowest yield in V_3 (2.6 kg) (Table 10).

Significant dissimilarity was observed in terms of yield per plant due to different zeolite treatments (Appendix V). Maximum yield per plant was found in T_2 (3.1 kg) and lowest yield in T_0 (2.8 kg) (Table 11). Berar and Posta (2011) argue that the yield of tomatoes was increased by adding 25% zeolite to substrate.

Combination of five tomato varieties and zeolite at different levels influenced significantly the yield per tomato plant (Appendix V). V_1T_2 (3.4 kg) exhibited maximum yield per plant while minimum was observed in V_3T_0 (2.4 kg) (Table 12).

Zeolites help to retain nutrients in the root zone to be used by the plants when required. Consequently this leads to more effective use of fertilizers by reducing their rates for the same yields, by prolonging their activity or finally by producing higher yields (Demir *et al.,* 2004). According to Leggo (2000), due to the high affinity of zeolites for nutrients, these minerals may be used in growth media to improve plant yields.

4.15. Yield per hectare

Yield per hectare was significantly varied in the case of five tomato varieties (Appendix V). Yield per hectare exposed statistically significant difference among five tomato varieties (V_1, V_2, V_3, V_4, and V_5) (Table 10). The highest yield was found from V_1 (93.1 ton) and the least production was exhibited in V_3 (80.3 ton) (Table 10).

Yield per hectare in different tomato varieties exposed statistically significant inequality among different zeolite doses (Appendix V). Maximum production was counted in T_2 (88.8 ton) treatment and the minimum was counted from T_0 (83.5 ton) at 80 DAT (Table 11). In T_2 treatment 6.2% and in T_1 treatment 3.6% more yield was achieved compared to control (T_0) at 80 DAT.

Increase of yield after zeolite application into the soil may be explained by its high affinity for the large cations like ammonium, potassium. Zeolites at the same time retain additional moisture in the soil for a long time, which also contribute in producing higher yield.

Tomato yield per hectare also exposed significant variation in response to the combined effect of different tomato varieties and zeolite application (Appendix V). Yield of different tomato varieties had revealed statistically significant variation among zeolite treatments (Table 12). In combination, the highest yield (95.5 ton) was found in Sweden 5 (V_1) with T_2 which showed 5.9% increased yield compared to control (V_1T_0) while the lowest value (78.4 ton) was found with control (T_0) in (V_3).

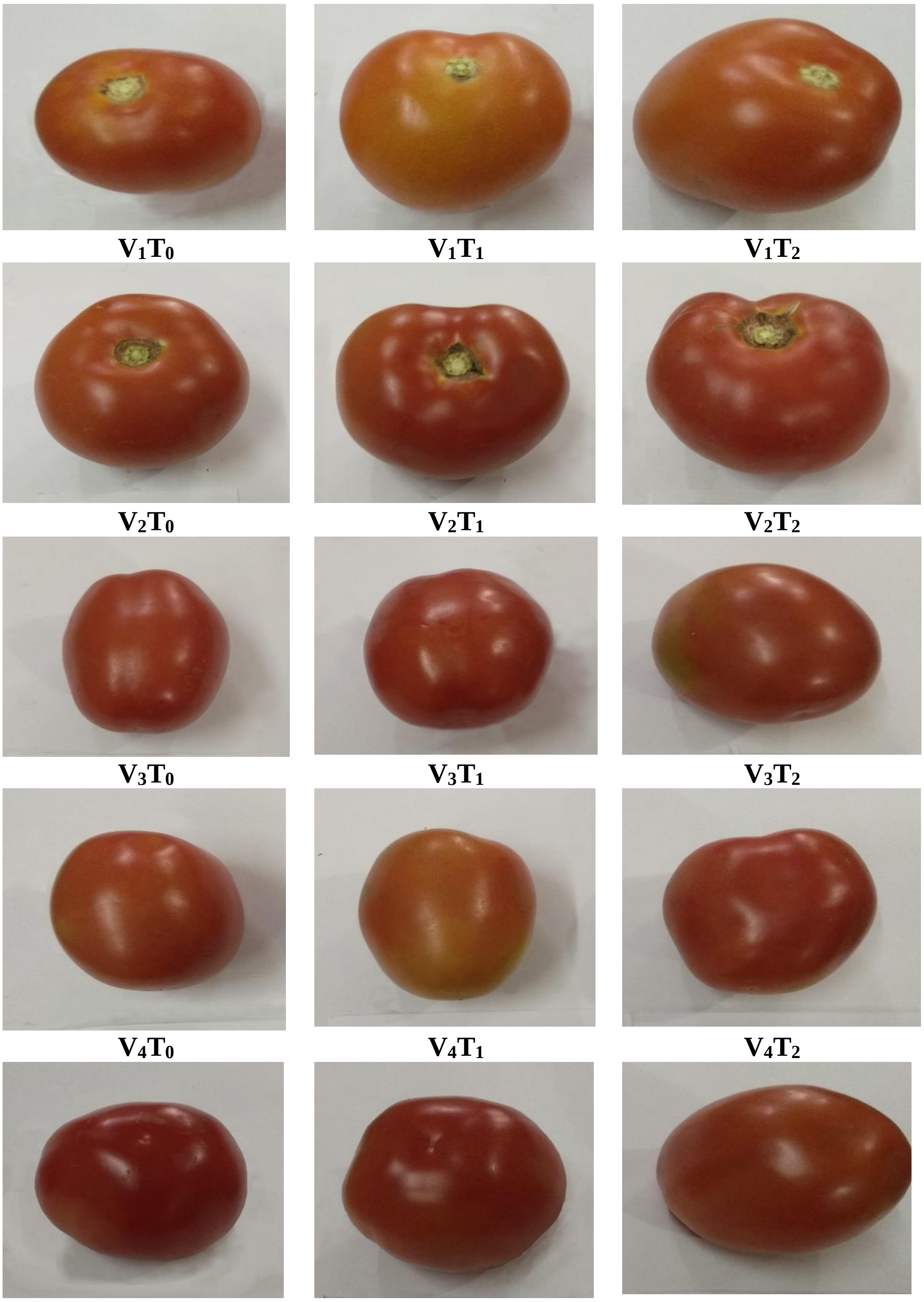
Mazur *et al.* (1984) also reported that zeolite increased the yields of potatoes, barley, clover, and wheat after adding to Ukrainian sandy loams. Torii (1978) stated that by using clinoptilolite-rich tuff as a soil conditioner, significant increases in the yields of wheat (13-15%), eggplant (19-55%), apples (13-38%), and carrots (63%) were reported when 4-8 ton/acre zeolite was used.

Table 12. Combined effect of tomato varieties and zeolite doses on fruit length, fruit diameter, single fruit weight, yield/plant, yield/hectare

Combinations	Fruit length (mm)	Fruit diameter (mm)	Single fruit weight (g)	Yield / plant (kg)	Yield /hectare(t)
V_1T_0	45.1 ij	48.2 f	83.6 g	3.1 bc	90.2 c
V_1T_1	48.5 hi	51.7 de	87.9 ef	3.3 ab	93.5 b
V_1T_2	51.9 de	55.4 c	89.7 cd	3.4 a	95.5 a
V_2T_0	50.6 e-g	56.6 bc	90.5 c	2.9 cd	87.3 d
V_2T_1	55.6 bc	58.6 b	92.6 b	3.1 bc	91.7 c
V_2T_2	57.7 a	61.9 a	96.6 a	3.3 ab	93.6 b
V_3T_0	51.4 ef	39.5 j	70.7 j	2.4 g	78.4 i
V_3T_1	53.6 cd	41.6 i	73.8 i	2.6 e-g	80.2 h
V_3T_2	56.9 ab	45.8 g	75.7 h	2.7 de	82.4 g
V_4T_0	48.8 g-i	37.5 k	68.6 k	2.5 fg	80.4 h
V_4T_1	52.6 de	40.8 ij	70.5 j	2.7 ef	82.6 g
V_4T_2	55.7 ab	43.7 h	73.4 i	2.8 de	85.6 ef
V_5T_0	43.2 j	47.3 fg	84.6 g	2.6 e-g	81.5 gh
V_5T_1	47.4 i	50.8 e	86.6 f	2.8 de	84.6 f
V_5T_2	49.6 f-h	53.4 d	88.5 de	2.9 cd	86.7 de
CV%	2.40	2.49	1.30	5.30	1.07
LSD	2.05	2.04	1.79	0.26	1.54

Here, V_1: Sweden 5; V_2: Apple Netherland; V_3 : TM 0.02 V_4: Roma VF and V_5: BARI Tomato-2 and T_0: No zeolite application (control); T_1: 12.5 kg/ha; T_2: 18.5 kg/ha

In a column means having similar letter (s) are statistically identical and those having dissimilar letter (s) differ significantly as per 0.05 level of probability.



V_1T_0 **V_1T_1** **V_1T_2**

V_2T_0 **V_2T_1** **V_2T_2**

V_3T_0 **V_3T_1** **V_3T_2**

V_4T_0 **V_4T_1** **V_4T_2**

V_5T_0 **V_5T_1** **V_5T_2**

Plate.2. Pictorial presentation of varietal performance due to zeolite application; here V_1: Sweden 5; V_2: Apple Netherland; V_3: TM 0.02 V_4: Roma VF and V_5: BARI Tomato-2 and T_0: No zeolite application (control); T_1: 12.5 kg/ha; T_2: 18.5 kg/ha

CHAPTER V

SUMMARY AND CONCLUSION

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5.1. Summary

In order to evaluate the effect of zeolite on the five tomato varieties, an experiment was conducted at Horticulture farm, Sher-e-Bangla Agricultural University, Dhaka during the period from October 2018 – March 2019. The two factorial experiment included five tomato varieties, Sweden 5 (V_1), Apple Netherland (V_2), TM 0.02 (V_3), Roma -VF (V_4), BARI Tomato-2 (V_5), and three treatments, i.e. Control (T_0), 12.5 kg Zeolite/ha (T_1), 18.5 kg Zeolite/ha. The whole experiment was sketched in Randomized Complete Block Design (RCBD) with three replications. Collected data were statistically analyzed for the evaluation of treatments for the selection of the best tomato varieties grown with the best treatment in different plots. The core of the experiment is illustrated in this chapter.

In terms of plant height, tallest plant was found at V_1 (138.8 cm) at 80 days after transplanting and the shortest was found at V_3 (97.2 cm). In the case of zeolite application tallest plant was found from T_2 (123.1 cm) and the shortest was found from T_0 (106.6 cm).In treatment combination, the tallest plant was obtained from V_1T_2 (148.3 cm) and the shortest was obtained from V_3T_0 (90.5 cm) at 80 DAT.

Considering tomato varieties, the maximum number of leaves per plant was found in V_1 (77.9) at 80 days after transplanting, and the minimum number of leaves was found in V_3 (65.5) at 80 days after transplanting. In the case of zeolite application maximum number of leaves was found in T_2 (73.5) at 80 days after transplanting and the minimum number of leaves was found in T_0 (68.0). In combined effect of varieties and zeolite, the highest number of leaves was found at V_1T_2 (81.7), and the lowest at V_3T_0 (63.0).

The maximum number of branch per plant was found in V_5 (8.3) at 80 days after transplanting and the minimum number of branches was found in V_3 (5.0) at 80 days after transplanting. In the case of zeolite application maximum number of branches was found in T_2 (7.3) at 80 days after transplanting and the minimum number of branches was found in T_0 (5.7). In combinations, the highest number of branches was found at V_5T_2 (9.3), and the lowest at V_3T_0 (4.3).

In terms of SPAD value, the highest SPAD value was found from V_2 (46.0) and the lowest was found from V_5 (30.8).In the case of zeolite application, the highest SPAD value was found from T_2 (40.2) and the lowest was found from T_0 (35.3). Concerning the combination treatment of varieties and zeolite highest SPAD value was found from V_2T_2 (48.3) and the lowest was recorded from V_5T_0 (28.3).

Considering tomato varieties, the longest period for first flowering was required in variety V_3 (42.9 DAT) while the shortest period was in V_4 (40.0 DAT). In the case of zeolite application, early flowering was recorded in T_2 (39.5 DAT) and delayed in control T_0 (41.4 days).In treatment combination V_1T_2 (39.0 DAT) required a minimum period for flowering initiation whereas maximum from V_3T_0 (43.9 DAT).

In the case of days to 1st fruit maturity, the longest period for the first maturity was required in V_3 (75.3 DAT) while the shortest period was in V_4 (71.4 DAT). In the case of zeolite application, early maturity was recorded in T_2 (71.4 DAT) and delayed in control T_0 (75.3 DAT).In treatment combination V_4T_2 (69.3 DAT) required a minimum period for fruit maturity whereas maximum from V_3T_0 (77.7 DAT).

The maximum number of cluster was found from V_1 (7.5) at 80 days after transplanting of tomato varieties and a minimum number of cluster was found from V_4 (5.8) at 80 days after transplanting. In the case of zeolite application, maximum number of cluster per plant was reported from T_2 (7.2), and minimum cluster number was found from control at T_0 (6.1). In the case of combinations, highest number of cluster was obtained from V_1T_2 (8.0) combination at 80 DAT of tomato varieties, and minimum was found from V_4T_0 (5.3).

The maximum number of flower per cluster was found from V_1 (9.6) at 80days after transplanting of tomato varieties and a minimum number of flower per cluster was found from V_5 (7.8). In the case of zeolite application, maximum number of flower per cluster was reported from T_2 (9.3), and minimum flower number was found from control at T_0 (8.1). In the case of combinations, maximum flower per cluster was obtained from V_1T_2 (10.1) combination, and minimum (7.1) was found from V_5T_0.

In terms of the number of fruit per cluster, the highest number of fruits per cluster was noted from variety V_1 (7.4) and the lowest was found from variety V_5 (5.6). In the case of zeolite application, a maximum number of fruits per cluster was recorded in T_2 (6.9) and the lowest was found from T_0 (5.8). In the case of combined treatment highest number of fruits per cluster was obtained from V_1T_2 (8.0) and the lowest was found at V_5T_0 (5.0).

In terms of the number of fruit per plant, the highest number of fruits was noted from variety V_1 (42.1) and the lowest was found from variety V_5 (35.3). In the case of zeolite application, a maximum number of fruits per plant was recorded in T_2 (39.6) and the lowest was found from T_0 (36.0). In the case of combined treatment highest number of fruits per plant was obtained from V_1T_2 (43.7) and the lowest was found in V_5T_0 (33.3).

Maximum fruit length was recorded from V_2 (54.6 mm) and shortest was recorded from V_5 (46.7 mm). In case of zeolite application of longest fruit was obtained from T_2 (54.3 mm) and the shortest was found from control, T_0 (47.8 mm). In terms of combinations longest fruit was found from V_2T_2 (57.7 mm) and the shortest was found from V_5T_0 (43.2 mm).

In terms of fruit diameter, maximum fruit diameter was reported from V_2 (59.0 mm) and the minimum was recorded from V_4 (40.7 mm). In case of zeolite application, fruit diameter was recorded maximum from T_2 (52.0 mm) while minimum was recorded from control, T_0 (45.8 mm).In case of combinations V_2T_2 (61.9 mm) was recorded as widest while V_4T_0 (37.5 mm) was recorded as lowest.

Maximum single fruit weight was recorded from V_2 (93.2 g) and least was recorded from V_4 (70.9 g). In terms of zeolite application of heaviest fruit was obtained from T_2 (84.8 g) and the minimum was found from control, T_0 (79.6 g). Considering the combination of zeolite and tomato varieties maximum fruit weight was found from V_2T_2 (96.6 g) and the lowest was found from V_4T_0 (68.6 g).

In respect of tomato varieties, maximum yield per plant was reported from V_1 (3.3 kg) and the minimum was recorded from V_3 (2.6 kg). In case of zeolite application, yield per plant has reached the peak from T_2 (3.1 kg) while least was recorded from control, T_0 (2.8 kg). Considering combined effect V_1T_2 (3.4 kg) produced highest yield per plant while V_3T_0 (2.4 kg) was recorded as lowest.

Concerning tomato varieties, maximum yield per hectare was reported from V_1 (93.1 ton) and the minimum was obtained from V_3 (80.3 ton). In case of zeolite application, yield per hectare has reached the top from T_2 (88.8 ton) while least was recorded from control, T_0 (83.5 ton). In T_2 treatment 6.2% and in T_1 treatment 3.6% more yield was obtained compared to control (T_0) at 80 DAT. Considering the combined effect of tomato varieties and zeolite, V_1T_2 (95.5 ton) produced the highest yield per hectare which shows 5.9% increased yield compared to control (V_1T_0) while V_3T_0 (78.4 ton) was recorded as the lowest.

5.2. Conclusion

Taking into consideration the above results, it can be concluded that tomato varieties displayed significant variation to zeolite application. According to the result, Sweden 5 (V_1) showed tallest plant, maximum leaf number, maximum cluster per plant, maximum flower per cluster, maximum fruit per cluster, maximum fruit per plant, and highest yield per plant and yield per hectare. On other side, zeolite applied at the rate of 18.5 kg/ha showed better result than other treatments among all the parameters. Sweden 5 (V_1) combined with zeolite at a rate of 18.5 kg per hectare produced better result among all other combinations. In a nutshell, it can be set out that Sweden 5 (V_1) was the better variety and T_2 (18.5 kg zeolite/ha) was the most excellent treatment for growth, and yield attributes of tomato.

5.3. Recommendation

Based on the research findings, recommendation is-

Zeolite can be used as potential soil amendment in farmer’s field to encourage better fertilizer and water use efficiency which ultimately leads to better plant growth and yield.

5.4. Suggestion

There is possible scope for considerable research in the context to explore the potential of zeolite in-

1. Efficient utilization in crop production
2. Soil productivity maintenance

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APPENDICES

Appendix I. Analysis of variance on plant height at different days after transplanting of Tomato

Source of Variation	Degrees of freedom	Mean Square for plant height (cm)				
		20DAT	35 DAT	50 DAT	65 DAT	80 DAT
Factor A (Tomato varieties)	4	197.812*	1046.447*	2246.234*	3284.862*	3026.675*
Factor B (Zeolite)	2	172.261*	313.418*	467.353*	693.410*	1015.963*
Interaction (A×B)	8	2.863*	10.282*	12.154*	8.586*	9.903*
Error	28	1.526	1.604	1.672	1.657	2.591

***: Significant at 0.05 level of probability**

Appendix II. Analysis of variance on leaf number of plant at different days after transplanting of Tomato

Source of Variation	Degrees of freedom	Mean Square for Leaf number(cm)				
		20DAT	35 DAT	50 DAT	65 DAT	80 DAT
Factor A (Tomato varieties)	4	17.478*	256.060*	246.660*	180.069*	245.186*
Factor B (Zeolite)	2	12.422*	31.814*	83.284*	117.221*	113.418*
Interaction (A×B)	8	0.228*	1.332*	1.255*	0.807*	3.249*
Error	28	1.146	1.128	1.294	0.827	3.836

***: Significant at 0.05 level of probability**

Appendix III. Analysis of variance on the number of branches per plant, SPAD value, Days to 1st flowering, and Days to 1st fruit maturity of tomato

Source of Variation	Degrees of freedom	Mean Square for Number of			
		Number of branches	SPAD value	Days to 1st flowering	Days to 1st fruit maturity
Factor A (Tomato varieties)	4	17.300*	282.669*	11.579*	22.078*
Factor B (Zeolite)	2	10.467*	92.049*	13.821*	52.467*
Interaction (A×B)	8	0.107*	0.940*	0.214*	0.494*
Error	28	0.190	1.901	0.908	0.924

***: Significant at 0.05 level of probability**

Appendix IV. Analysis of variance on the number of cluster per plant, Number of flower/cluster, Number of fruit/cluster, Number of fruit/plant of tomato

Source of Variation	Degrees of freedom	Mean Square for Number of			
		Number of cluster	Number of flower/ cluster	Number of fruit/ cluster	Number of fruit/plant
Factor A (Tomato varieties)	4	7.828*	13.234*	5.195*	48.329*
Factor B (Zeolite)	2	3.710*	4.225*	3.605*	37.357*
Interaction (A×B)	8	0.122*	0.022*	0.115*	0.899*
Error	28	0.148	0.336	0.139	0.770

***: Significant at 0.05 level of probability**

Appendix V. Analysis of variance on fruit length, fruit diameter, single fruit weight, yield/ plant, yield/hectare of tomato

Source of Variation	Degrees of freedom	Mean Square for Number of				
		Fruit length(mm)	Fruit diameter (mm)	Single fruit weight (g)	Yield/ plant (kg)	Yield/hectare (t)
Factor A (Tomato varieties)	4	108.775*	503.976*	831.695*	0.810*	266.481*
Factor B (Zeolite)	2	161.481*	143.750*	101.973*	0.422*	102.335*
Interaction (A×B)	8	1.394*	1.254*	1.494*	0.01*	0.966*
Error	28	1.483	1.481	1.149	0.026	0.850

***: Significant at 0.05 level of probability**