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Effects of zeolites on the growth of cucumber and tomato seedlings

by

Lisa Rydenheim

Fakulteten för landskapsplanering, trädgårds- och jordbruksvetenskap

SLU-Alnarp

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Lisa Rydenheim

Supervisor: Helena Karlén
Examiner: Håkan Asp
Department of Horticulture
Swedish University of Agriculture (SLU), Alnarp
Box 44
SE-230 53 Alnarp

Summary

Zeolites are a group of minerals, with a special structure giving them properties like ion-exchange capacity and the ability to act as molecular sieves. Due to these properties zeolites have a wide range of applications in various areas.

ZeoPro is a commercial product, based on natural zeolite minerals and developed as a plant growth medium. It is claimed to improve plant performance, utilize nutrients more efficient 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. The results showed some increase in growth when ZeoPro was added to the growth medium. In cucumber the growth increased with increasing amount of ZeoPro, generating the largest plants with 20% ZeoPro and the smallest in the control group without ZeoPro. 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 addition of ZeoPro were clearly smaller than the other groups.

Sammanfattning

Zeoliter är en grupp mineraler med speciell struktur vilken ger dem egenskaper som jonbytarkapacitet och möjlighet till molekylsiktning. På grund av dessa egenskaper har zeoliter ett stort antal skilda användningsområden.

ZeoPro är ett planteringsmedia baserad på naturliga zeoliter. Det sägs ge kraftfullare plantutveckling, högeffektivt näringsutnyttjade och reducera näringsläckage till omgivningen. I den här studien utvärderas effekten av ZeoPro på småplantor av gurka och tomat, när 5%, 10% och 20% ZeoPro blandades i växtsubstratet. Resultaten visade på en viss ökad tillväxt vid tillsats av ZeoPro. På gurka ökade tillväxten med ökat innehåll av ZeoPro och gav störst plantor vid 20% innehåll av ZeoPro och minst plantor i kontrollgruppen utan tillsats av ZeoPro. I tomat fanns de största plantorna i 5%-gruppen tätt följda av 10%- och 20%-grupperna. Plantorna i kontrollgruppen, utan tillsats av ZeoPro, var tydligt mindre än de andra grupperna.

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Contents

Introduction

The topic of this report is zeolites and their application in horticulture. Zeolites are a group of minerals built up by aluminosilicates. They have a rigid 3-dimentional, crystalline structure consisting of a network of interconnected tunnels and cages. The structure gives zeolites special properties like a high ion-exchange capacity and the ability to act as molecular sieves (ZeoponiX, 2000). Due to these properties zeolites have a wide range of applications in various areas. This report covers background information about zeolites, such as structure, properties, occurrence and applications.

The results of a minor practical pre study will also be presented in this report. A commercial product called ZeoPro, based on natural zeolite minerals and developed as a plant growth medium, was used. It is claimed to improve plant performance, utilize nutrients more efficient and reduce nutrient leaching to the environment (ZeoponiX, 2000).

The technology behind this product was first developed by the National Aeronautics and Space Administration (NASA) and then further developed by the American company ZeoponiX, Inc.. The distributor of ZeoPro in Sweden and Norway is DIGITECH Rental AB.

Several experiments with ZeoPro have been carried out in the U.S. for ZeoponiX, in turf, floriculture and vegetable applications. In a Swedish investigation the influence of ZeoPro on the development of spruce and fur seedlings have been evaluated (Söderberg, 2004).

The aim of this pre study was to investigate if ZeoPro effects the growth of cucumber and tomato seedling if 5%, 10% or 20% of ZeoPro was mixed into the growth medium, which in this case was a peat:sand mix. The three treatments were compared with a control with no addition of ZeoPro. The growth was evaluated in several ways; height, leaf number, leaf area, fresh weight and dry weight.

Background

Physical and chemical properties of Zeolites

Zeolites are a group of hydrated aluminosilicates of the alkali and alkaline earth metals (GSA Resources, 2000). They are crystalline minerals having an infinite, open, three-dimensional structure (Mumpton, 1998). The silica and alumina anions, SiO_4^{4-} and AlO_4^{5-}, form a tetrahedral framework, strongly bonded at all corners. This structure forms a network of interconnected tunnels and cavities with an almost uniform diameter from about 3-12 Å (GSA Resources, 2000). The open structure of zeolites makes it different from e.g. the tightly packed framework structures of quartz and feldspar. Zeolite species with void volumes of 50% are known.

The presence of aluminium exchanging silicon results in a negative charge, which is balanced by positively charged cations (Demir et. al., 2004). Most of the cations belong to the alkaline earth metals like Na, Ca, K and in some cases Ba and Sr (Bengtsson, 1998).

Loosely bound molecular water is also present in the structure of all natural zeolites, surrounding the exchangeable cations in the large pore spaces (Mumpton, 1985). Zeolites are characterized by their ability to lose and absorb this water without damage to their crystal structures (Mineral Gallery, 2005). This feature has given them its name. The name Zeolites, which is Greek in origin, means “boiling stones” from zeo (to boil) and lithos (stone) and it refers to the ability of water to be reversibly driven of (The MCS Zeolite Page 2005).

A special aspect of the zeolite structure is that it can act as a molecular sieve. A molecular sieve is a material with selective adsorption properties capable of separating components in a mixture on the basis of a difference in molecular size and shape (Anonymous, 2005). Under normal conditions, the large cavities and entry channels of zeolites are filled with water molecules. The water can be removed, usually by heating to 3000 to 4000ºC for a few hours. Once this is done molecules having diameters small enough to fit through the entry channels are readily adsorbed on the inner surface of the vacant cavities. Molecules too large to pass through the entry channels are excluded, giving rise to the “molecular sieving” (Mumpton, 1985).

Another important property of zeolite is the ability to exchange cations. The alkali and alkaline earth cations in the zeolites, that compensate the negative charge of the silicon-aluminium oxygen framework, are able to exchange with other cations. Most natural zeolites have a cation exchange capacity from 200-400 meq/100g (Mumpton, 1998). The smaller the silicon to aluminium ratio in the zeolite framework, the greater the ion-exchange capacity. This principle is not always kept however. Experiments have shown that ion-exchange capacity not only depends on the Si/Al ratio, but also on ion-exchange form of the zeolite. For example, some papers report that ion-exchange capacity was reduced by the presence of potassium (Kalló & Sherry, 1988).

It is important to remember that the physical and chemical properties vary a lot between different types of zeolites. Crystal structure and chemical composition account for the primary differences. One difference which is particularly important is the composition of exchangeable cations. Particle density, cation selectivity, molecular pore size and strength are other properties that can differ depending on the zeolite in question. But variation does not only occur between different types of zeolites but also in the physical and chemical properties of zeolites in the same group. Source plays a large role in these variations (ZeoponiX, 2000).

Occurrence

There are about 150 different zeolites of which approximately 60 are represented as naturally occurring minerals (Thomasson, 1998). In nature, zeolites generally originate from a volcanic glass precursor (Kalló & Sherry, 1988). They are often formed during a very low grade metamorphism. Some form from just subtle amounts of heat and pressure and can just barely be called metamorphic, while others are found in obviously metamorphic regimes (Mineral Gallery, 2005). The most common natural zeolites are analcime, chabazite, clinoptilolite, erionite, modenite, laumontite and phillipsite (Thomasson, 1998).

Natural zeolites mainly occur in three types of geological deposits. The first one is in volcanic rocks. The second type as sediments. They can either be kilometre tick land-sediments or deep-sea sediments, in the Atlantic sea and the Pacific Ocean. The third type of deposits is in thermally active areas like in New Zeeland (Thomasson,1998).

Today only the sedimentary findings on land are profitable for mining. Deposits of natural zeolites in sedimentary rocks have been found on all continents in more than 40 countries, for example the US, Japan, Cuba, Russia, Hungary, Italy, Korea, Taiwan, Bulgaria, Mexico and South Africa (Thomasson, 1998). The world stockpile of natural sedimentary zeolite-rich rocks is great, probably billions of tons (Kalló & Sherry, 1988). The commercial use is still in its infancy, but more than 300 000 tons of zeolite-rich tuff is mined each year (Mumpton, 1985). As expected, most of it is used in countries with own assets of sedimentary zeolites (Thomasson, 1998).

Industry has mimicked some of the natural zeolites and formed many new synthetic zeolites targeted towards very specific purposes (The MCS Zeolite Page 2005). Some of the most common synthetic zeolites are zeolite A,X,Y and ZMS-5 (Demir et. al., 2004).

Applications

History

Natural zeolites were first discovered and recognized as distinct mineralogical species by the Swedish mineralogist, Freiherr Axel Fredrick Cronstedt in 1756 (Demir et. al., 2004). The utilization of the mineral, however, was well established long before that. There are many examples around the world were zeolite rock have been used for building material as long as 4000 years ago. The knowledge of zeolites intrinsic chemical reactivity, adsorptivity and cation exchange properties have more recently been exploited by the 20th-century man (Kalló & Sherry, 1988).

As early as in the mid-1800s chemists were investigating the cation-exchange and molecular sieving properties of natural zeolites. The problem was that zeolites was sufficiently abundant for experimental purposes, but not present in amounts that could support commercial operations. The non-availability of natural zeolites prompted the chemists to turn to synthesis as a mean of obtaining a steady supply of these materials. For example, R. M. Milton synthesized a zeolite that was called Linde's Type A zeolite, which today is one of the mainstays of the worldwide molecular sieve business (Kalló & Sherry, 1988).

As the synthetic zeolite business increased in the late 1950s geologists discovered major deposits of natural zeolites in near-surface sedimentary rock. It made it possible to use relatively inexpensive surface-mining techniques. This opened up for low-cost applications using the natural materials, in addition to those being developed for the dollar-a-pound synthetic products. After these discoveries the Zeolite Appreciation Society began to grow and efforts to exploit these natural recourses in various areas of agriculture and industrial technology were made in many countries (Kalló & Sherry, 1988).

During the last 40-50 years zeolitic materials have obtained great application in industry, agriculture and environment protection. Natural zeolites have received considerable attention in both technical and popular press as this generation's "wonder mineral" (Kalló & Sherry, 1988). Due to its wide range of application possibilities zeolites have been referred to as the magic rock, la roca magica. The applications make use of one or more of the following properties: cation exchange, adsorption and related molecular sieving, catalytic, dehydration and rehydration and finally biological reactivity (Mumpton, 1999).

The oldest application of natural zeolites is as building material and it is still being used as building stone and as lightweight aggregates and pozzolans in cement and concretes (Mumpton, 1999).

Industry

In industry, natural zeolites have a wide range of applications. They are used for drying and purification of gaseous flows, including gases containing acidic substances. Their great adsorption selectivity for H_2O makes them excellent desiccants. They are for example used to remove water and carbon dioxide from sour natural gas (Mumpton, 1999).

Enrichment of oxygen and nitrogen from air is also an important field. The zeolites possess heightened adsorption capacity for molecular nitrogen compared with molecular oxygen. This allows the production of air containing different and increased contents of nitrogen and oxygen (Kalló & Sherry, 1988). Oxygen enriched air can be used in hospitals, in fishbreeding and transportation, and in poorly ventilated restaurants (Mumpton, 1999).

Natural zeolites are also used as fillers in paper, rubbers and polymers.

Clinoptilolites may be used in the harnessing of solar energy. They desorbs water at heating by the solar radiation (during the day) and release heat by adsorption of water vapour during the (during the night) (Kalló & Sherry, 1988).

Encapsulation of gases is another interesting application. At elevated temperatures the openings in the zeolites structure widens. When the temperature is decreased the gas molecules are trapped and can be stored in the zeolites. This is an efficient method of gas storage which has become more important with the development of new aircraft techniques and the conquest of space (Kalló & Sherry, 1988).

Today mostly synthetic zeolites are used as catalysts. The two principal uses of synthetic molecular sieves are the purification of gaseous hyrocarbons and the preparation of catalysts for petroleum refining (Mumpton, 1999). 1.4 million tons of synthetic zeolites are produced annually for catalyse, ion exchange and adsorption. The technically and economically most important application for synthetic zeolites are the petrochemical industry to “crack” or break down various raw materials to form specific chemicals like gasoline. More than 98% of the world production of oil is cracked with zeolites (Thomasson, 1998).

Protection of environment

Environmental protection becomes more and more important as the increasing amounts of harmful matters pollute the air and waters of our planet. Natural zeolites have been found to have many application possibilities in this field, as they are able to purify air and water media. They are for example widely used for the purification of drinking, municipal and industrial wastewaters (Kalló & Sherry, 1988).

Zeolites also have an important role in treatment of nuclear waste and fallout. They have superior selectivity for certain radionuclides and are resistant to degradation by nuclear radiation (Mumpton, 1999).

Because natural zeolites easily adsorb large cations they are effective in filtering agents to remove lead, copper, cadmium and other toxic matters from the environment. It has been shown that clinoptilolite adsorb heavy metals, decreasing the content in soil and plants (Kalló & Sherry, 1988).

Other applications

Numerous natural zeolite-containing products have come on the market in the U.S., Japan, Hungary, Cuba and Germany. The most common is pet litters that take up water and odour-causing NH_3 from animal urine. The zeolites have the ability to exchange NH_4^+ from aqueous solutions and thereby preventing the release of NH_3 into the atmosphere.

Several deodorizing agents have also been marketed. They can remove malodours from example shoes, garbage cans and refrigerators (Mumpton, 1999).

Large quantities of the synthetic zeolite, zeolite A, are used as ion exchangers in laundry detergents to exchange magnesium and calcium ions from hard water with their own sodium ions (NASAexplores, 2003).

Zeolites are sometimes used as paint components with anti-corrosive properties (Demir et. al., 2004).

Some medical applications have also been developed for certain zeolites. Fore example as effective filter media to remove NH_4^+ from the dialysate of kidney patients during hemodialysis (Mumpton, 1999).

Agriculture

All over the world agriculturists increase their efforts to expand crop and animal production. More and more attention is being paid to various mineral materials as soil amendments and dietary supplements in animal husbandry. The zeolite group is a group of minerals with considerable potential in a wide variety of agricultural processes. They are fast becoming the subject of serious investigations in dozens of agricultural laboratories worldwide (Mumpton, 1985).

Animal husbandry

Many experiments have been carried out on the application of natural zeolites as dietary supplements for several types of domestic animals. Despite the lack of statistical significance, numerous studies strongly suggest that the addition of certain zeolites to the diets of swine, poultry and ruminants result in improvements in growth and feed efficiency. In addition, the occurrence of intestinal disease among young animals appears to be less when zeolites are a part of the daily diet. The exact functions of zeolites in these phenomena are not well understood (Mumpton, 1985).

Many studies have also reported noticeable decrease in excrement malodour when zeolites are used as a dietary supplement. Similar results were noted when zeolites were added directly to cattle feedlots. These effects are a result of zeolites high selectivity for the ammonium ion. This suggests that not only can healthier and less odoriferous environments be achieved, but that the nitrogen-retention ability of the manure can be important as well (Mumpton, 1985).

Plant production

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.

The agrotechniques of today uses huge amounts of fertilizers and other chemical preparations. These are intensely washed out by rain and irrigation water, and thereby polluting the environment (Kalló & Sherry, 1988). 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).

Especially clinoptilolite have a pronounced selectivity for cations, such as ammonium and potassium. This has been exploited in the preparation of slow-release chemical fertilizers. For example, Hershey et. al., (1980), showed that potassium-enriched clinoptilolite added to a potting medium for chrysanthemums acted very similar to a slow-release fertilizer. The same fresh-weight yield was achieved with a one-time addition of clinoptilolite as with a daily irrigation of Hoagland's solution, containing 238 ppm K, for three month.

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).

Urea is one of the most commonly used nitrogen fertilizers. It is very soluble in water and can be leached through the root zone. In addition, urea is converted into ammonium ions by a microbial enzyme found in most soils. Soil bacteria then convert these ammonium ions into readily leachable nitrate ions. Using zeolitic rock in fertilizer may prevent these nutrient losses (Eberl, 1993). The rate of nitrogen release from zeolites is slowed in three ways: (1) by containing urea in the rock pores and zeolite structures, thus preventing the leaching of urea from the root zone; (2) by slowing down the conversion of urea by soil microbial enzymes, thus delaying the formation of ammonium ions; and (3) by taking up ammonium ions into exchange sites in the zeolite, thus protecting them from nitrifying bacteria (Bengtsson, 1998, Eberl, 1993).

Considerable attention has been paid to so called zeoponic mixtures of NH_4^+- or K^+-exchanged natural zeolites and phosphate minerals e.g. apatit (Mumpton, 1999). Apatite is a calcium phosphate, and by mixing it with a zeolite having exchangeable ions like ammonium, phosphate ($H_2PO_4^-$) can be released to plants. The approximate reaction in soil solution is as follows: (P-rock) + (NH_4-zeolite) → (Ca-zeolite) + (NH_4^+) + ($H_2PO_4^-$). The zeolite takes up Ca^{2+} from the phosphate rock, thereby releasing both phosphate and ammonium ions.

Zeolites ability to retain moisture is also very important in plant growing. They may hold water up to 60% of their weight due to the high porosity of the crystalline structure. Zeolites assure a permanent water reservoir, providing prolonged moisture during dry periods. The also promote a rapid re-wetting and improve the lateral spread of water into the root zone during irrigation. This reduces the quantity of water needed for irrigation.

The porous structure of natural zeolites also helps to keep the soil well aerated. Unlike other soil amendments (e.g. lime) zeolites does not eventually break down, but remains in the soil to improve nutrient retention. This can significantly reduce costs of water and fertilizers over time. (Demir et. al., 2004).

Another beneficial property of zeolites in plant growing is its ability to trap heavy metals in the soil by ion-exchange and thereby preventing their uptake into the food chain. The origin of the heavy metals is often municipal and industrial sewage sludge used as a nutrient source.

Research have also shown that addition of clinoptilolite to soils contaminated with radioactive strontium (Sr^{90}) resulted in a significantly decrease in plant uptake of strontium (Mumpton, 1985, Thomasson, 1998).

The high adsorption capacities and high ion-exchange capacities of many zeolites also makes them effective carriers of herbicides, fungicides and pesticides (Mumpton, 1985).

ZeoPro

The zeoponic systems mentioned above have been utilized by the National Aeronautics and Space Administration (NASA). They have taken the zeolite-apatite reaction one step further and prepared a substrate consisting of a specially cation-exchanged clinoptilolite and a synthetic apatite containing essential trace nutrients for use as a plant-growth medium in shuttle flights. This formulation may well be the preferred substrate for vegetable production aboard future space missions and in commercial green houses (Mumpton, 1999).

A company called ZeoponiX, Inc. has further developed this technology and is marketing a product called ZeoPro. DIGITECH Rental AB is the retailer of this product in Sweden and Norway.

ZeoPro is a combination of growth medium/fertilizer/soil amendment. The product is granular and includes a nutrient amended natural zeolite (clinoptilolite) and synthetic apatite. It is loaded with N P K 0.1% – 0.1% – 0.6%. The specific properties of the product can be seen in table 1.

The clinoptilolite has its origin in Arizona and is chosen for its desirable properties. It is high in K low in Na to avoid toxic affects on the plants. It also has a high CEC and durable particles.

The synthetic apatite contain calcium hydroxyl phosphate ($Ca_{10}(PO_4)_6(OH)_2$) plus some micro and trace nutrient substitutions.

According to the company, ZeoponiX, Inc., ZeoPro could be used in numerous areas like golf greens, sport fields, greenhouses, nurseries, pot plants, flower beds, lawns and vegetable growing. It is claimed to improve the plant performance, utilize nutrients more efficient and reduce nutrient leaching to the environment (ZeoponiX, 2000).

Tab 1. *Properties of ZeoPro*

Particle size	0,4-2,4mm
Volume	780-1050kg/m^2
Specific Surface Area	40m^2/g
CEC	1,65meq/g

Several experiments with ZeoPro and it precursors have been carried out in the U.S. for the company ZeoponiX, Inc. on turf, floriculture and vegetable applications. Many of these experiments have shown that different rates of zeoponic substrates with no supplemental fertilization can produce plants similar in size and quality to conventionally produced plants fertilized with nutrient solution. Summaries of the results are available on their webpage (ZeoponiX, 2000). However, the details of these experiments are considered proprietary and have not been released.

In a Swedish investigation done by Söderberg (2004), the effect of ZeoPro on spruce and fur seedlings was evaluated. Two, five and ten % of ZeoPro were mixed with peat and compared with a control group planted in pure peat. The four groups had the same conditions in terms of light, water and fertilization. Measurements of shoot length, stem diameter and dry weight was carried out every 3-4 weeks at totally 4 occasions.

The results showed that the plants grown in a mixture of ZeoPro and peat were larger than the ones grown in pure peat. The plants grown with ZeoPro were approximately 3 weeks earlier in development than the ones grown without ZeoPro. Söderberg believes that this advantage probably is due to the fact that these plants had access to a larger amount of nutrients than the ones grown in pure peat (Söderberg, 2004).

Aim

The aim of this pre study was to investigate if ZeoPro effects the growth of cucumber and tomato seedlings when 5%, 10% or 20% is added to the substrate, compared to a control grown in a mixture of peat and sand (3:1) without addition of ZeoPro. The growth will be evaluated in several ways; height, leaf number, leaf area, fresh weight and dry weight.

Materials and Methods

Experimental design

The study was carried out at SLU in Alnarp from the 6/2 to 13/3 2006. Two plant species were used; cucumber (*Cucumis sativus*) and tomato (*Lycopersicon lycopersicum*). 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.

In total, 32 cucumber plants and 32 tomato plants were used, which means four groups with 8 plants per group (table 2). The plants of the control group were planted in a mixture of 2/3 unfertilized, limed peat and 1/3 sand. The treatments were 5%, 10% and 20% of ZeoPro added to the peat:sand mixture, used as a control.

Tab 2. *Experimental setup*

ZeoPro	**0%**	**5%**	**10%**	**20%**
Cucumber	8	8	8	8
Tomato	8	8	8	8

Implementation

The substrate used as a control was made by mixing 2/3 unfertilized, limed peat (75 litre) and 1/3 (37,5 litre) sand together with 0,29kg lime powder in a cement-mixer for 20 minutes. The amount of lime was calculated to regulate the pH to between 5-5,8. The mixture was then poured onto a plastic tarpaulin and used to fill 23, 1 litre pots. 10 of the pots were used for cucumber, 12 for tomato and one for observation. The plan was to have 10 plants for each group. Due to lower germination rate than expected, the group size had to be reduced to 8 plants.

25 litre of each mixture with ZeoPro was prepared. For the 5%-mixture, 1,25 litre ZeoPro and 23,75 litre peat:sand was mixed in the cement-mixer for 4 minutes. The mixture was then poured out and used to fill 23 pots. The mixing with 10% and 20% were carried out in the same way, using 2,5 litres and 5 litres of ZeoPro respectively.

The pots were placed on trays with each group of plants on one tray. Every pot was then given a number. The trays were placed on a bench in a greenhouse compartment and watered thoroughly.

The seeds were bought from Olssons Frö AB and the name of the cultivars was; greenhouse cucumber DRL 9471 F1 and tomato 'Avengance' F1. The cucumber seeds were soaked in water for one hour before sowing. After sowing, the seeds were covered with a small amount of peat:sand mixture and the pots were watered again.

Growing conditions

The pots were kept in a greenhouse with a day and night temperature of 20°C and a relative humidity of approximately 50% during the whole study. However, since the trial was carried out during the winter the temperatures could differ depending on the outside weather.

In the first two weeks there was no need for irrigation. After that the plants were watered once a week with 150ml of pure water per pot. No supplementary light from lamps was used.

Measurements

The growth of the plants was evaluated once a week throughout the trial, in total five times for cucumber and six times for tomato. The first time only plant emergence or not was noted. During the rest of the study, plant height was measured and leaves counted (the cotyledons were not included). For cucumber only leaves that were larger than 2 cm were counted.

At the end of the study, fresh weight, dry weight and leaf area were measured for each plant. The plants were cut off at the soil surface and the fresh weight was immediately determined. After that, the leaves were removed with a scissor (including the cotyledons). They were cut into appropriate size and the leaf area was measured with an area meter (LI-COR, MODEL LI-3100 AREA METER). Each plant was put in a paper bag and dried in an oven at 80ºC for approximately 36 hours. After that the dry weight was measured.

Statistical analyses

The values of all measurements were analyzed in Minitab. Mean and standard deviation was calculated and Tukey simultaneous tests were carried out at a 5% level. Bars in the figures marked with the same letter are not significantly different.

Results

Cucumber

General appearance

The cucumber plants looked rather healthy at the end of the trial. The 20% and 10% groups had started to develop ovaries in the leaf axils.

The 0% and 5% group showed no clear symptoms of deficiency. However, especially the 0% group was very small. They were probably stunted in growth due to nutrient deficiency.

Some deficiency symptoms were visible in the 20% and 10% group. Yellow and later dead spots at the edge of the older leaves developed during the last week of the trial. This symptom could indicate phosphorus or manganese deficiency (Caspersen, 2006, Asp, 2006)

Increase of plant height

The height development of cucumber plants is shown in fig. 1. The 10% and 20% group clearly grow faster from day 14 and forward and ends up at heights between 150-200 mm.

The plants belonging to 0% and 5% groups grew more slowly and the final heights were in average less than 150 mm. The control plants grew faster than those belonging to the 5% group until the last measurement, when the average height for the 5% group was higher.

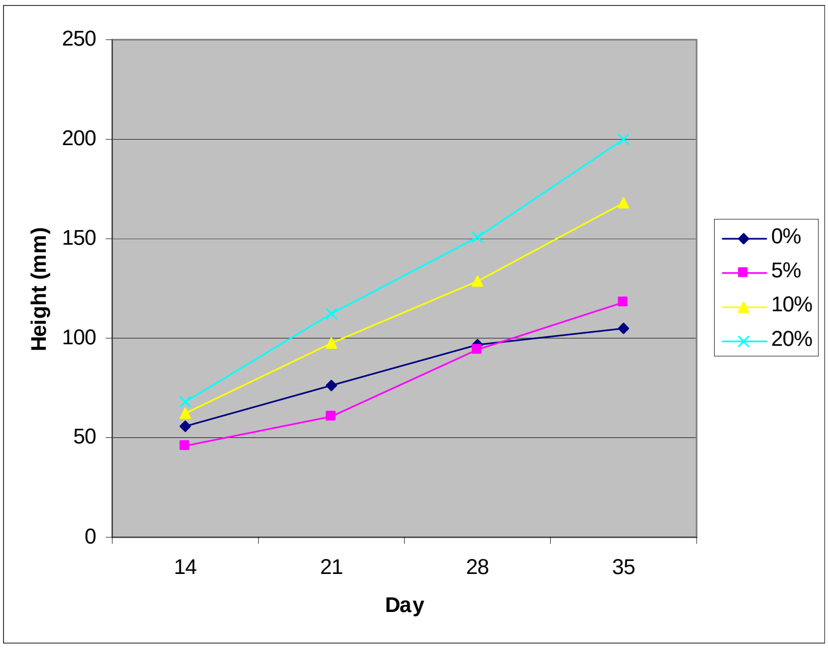

Fig 1. *Average height for cucumber plants grown in a peat:sand mixture with the addition of 0%, 5%, 10% and ZeoPro, measured once a week (n=8)*

Development of leaves

The average number of leaves per cucumber plant, counted at three occasions during the trial, is shown in fig. 2. The figure shows that the 10% and 20% groups develop faster during the whole trial. At the end of the trail the plants from both groups have in average 4 leaves.

The 0% and 5% groups initially develop quit similarly, but at the last measurement the 5% group have more leaves than the 0% group. Most of the plants in the 0% group had 3 leaves or less and the plants in the 5% group had between 3 and 4 leaves.

The development of leaves only shows the number of leaves and does not specify the size of the leaves, except that they are more than 2 cm long. The measurements of the leaf area (fig. 6) give a better picture of the actual size of the plants. However it does only show the size at the end of the trial and not the development over time.

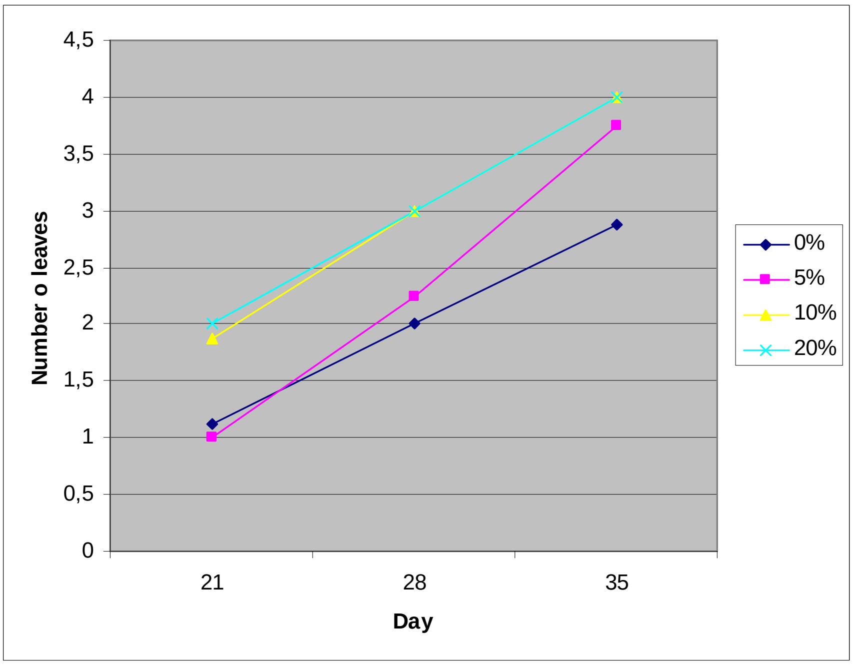

Fig 2. *Average number of leaves on cucumber plants grown in a peat:sand mixture with the addition 0%; 5%, 10% and 20% ZeoPro, counted once a week (n=8).*

Final height

The final height of the cucumber plants is shown in fig. 3. The plants in the 20% group are highest at approximately 200 mm whereas the 0% group is the smallest at around 100 mm. A significant difference can be shown between the 20%, 10% and 5% group but the difference between 0% and 5% is not significant.

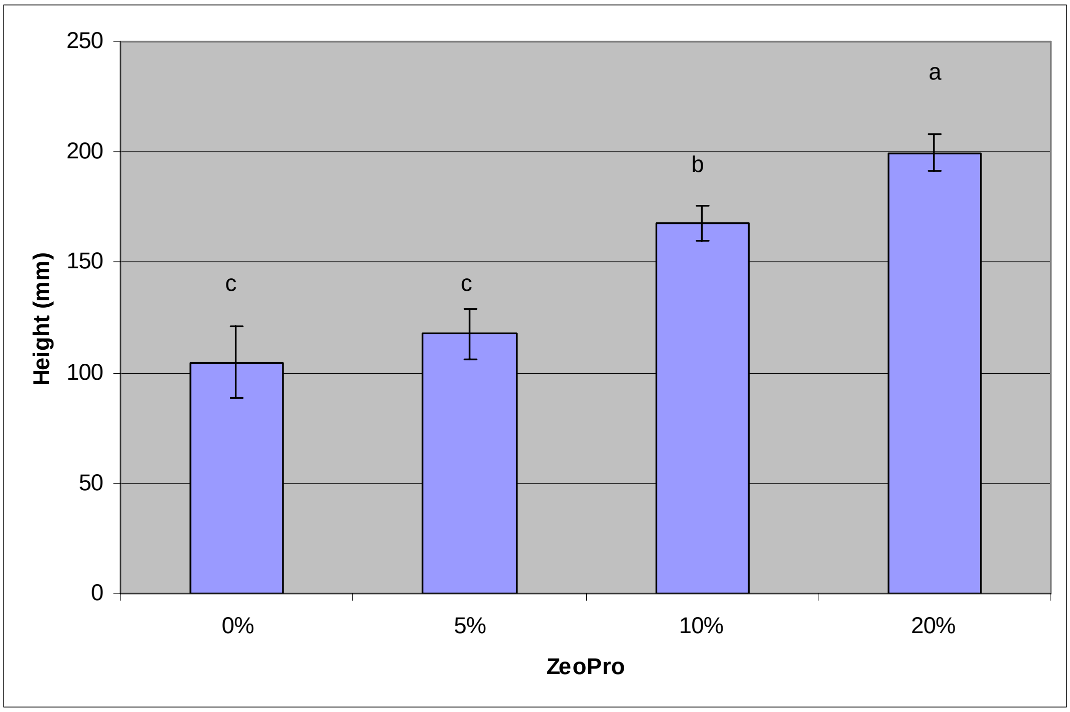

Fig 3. *Average height in mm of 5 weeks old cucumber plants grown in a peat:sand mixture with the addition 0%, 5%, 10% and 20% ZeoPro (n=8).*

Fresh weight

The fresh weight of the cucumber plants are presented in fig. 4. The 10% and 20% groups clearly have the highest fresh weights at approximately 9-10g per plant. In the 5% group the fresh weight is approximately 5g and in the 0% it is about 3g. A significant difference can be shown between all groups.

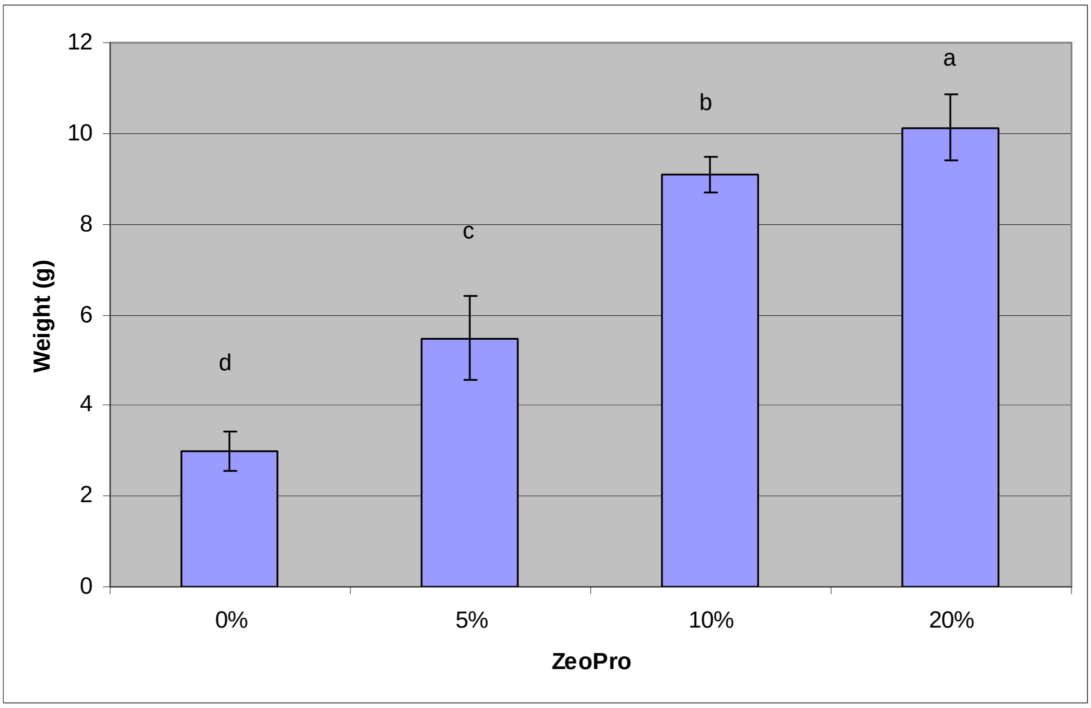

Fig 4. *Average fresh weight in g of 5 weeks old cucumber plants grown in a peat:sand mixture with the addition 0%, 5%, 10% and 20% ZeoPro (n=8).*

Dry weight

The dry weight of the cucumber plants are presented in fig. 5. The dry weights indicate the same as the fresh weights. The 10% and 20% groups have the highest values, about 0,7-0,8g. The values of the 0% and 5% groups are a bit lower, approximately 0,2-0,3g.

However, the result from this part may not be so reliable. The scale used only showed the weight with one decimal precision and the standard deviation bars shows that there was quit a large variation within each group.

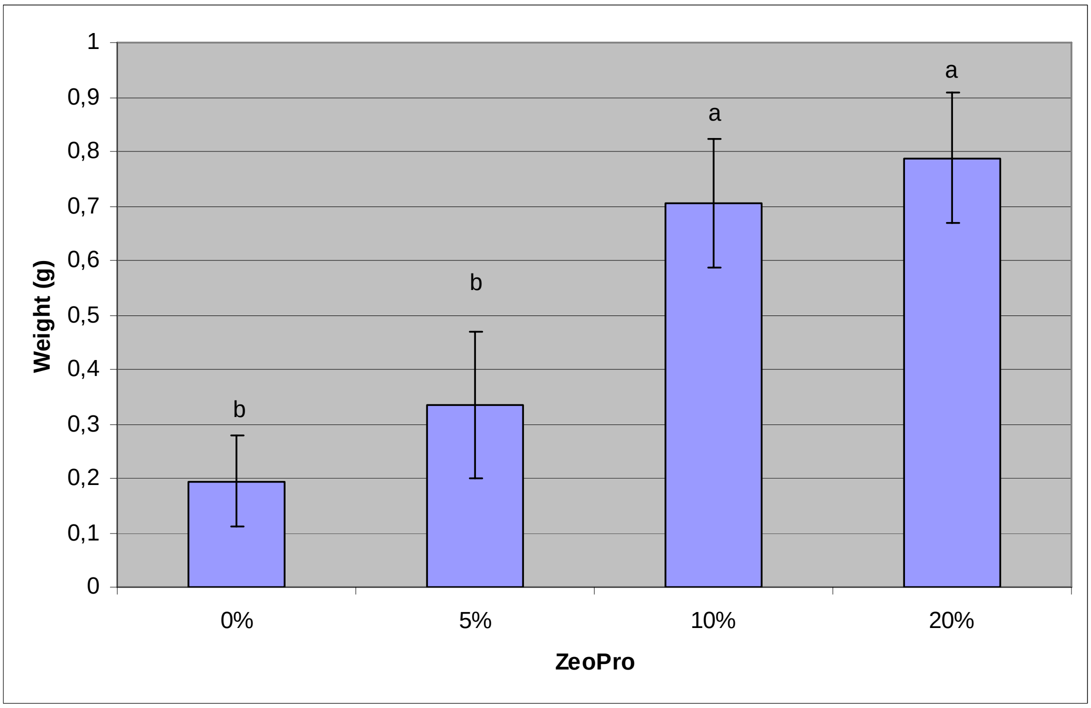

Fig 5. *Average dry weight in g of 5 weeks old cucumber plants grown in a peat:sand mixture with the addition 0%, 5%, 10% and 20% ZeoPro (n=8).*

Leaf area

The leaf area of the cucumber plants are presented in fig. 6. The leaf area also indicates that the 10% and 20% groups have the largest plants. The area is measured to be around 300 cm^2 for each of these two groups. For the 5% group the leaf area is approximately 200 cm^2 and for the 0% group it is about 100 cm^2.

The leaf area also complements fig. 2 of the leaf development. That figure indicates that the number of leaves in the 5% group were almost the same as in the 10% and 20% at the end of the trial. Figure 6 however, shows that the average size of the leaves is smaller for the 5% group compared with the 10% and 20% groups.

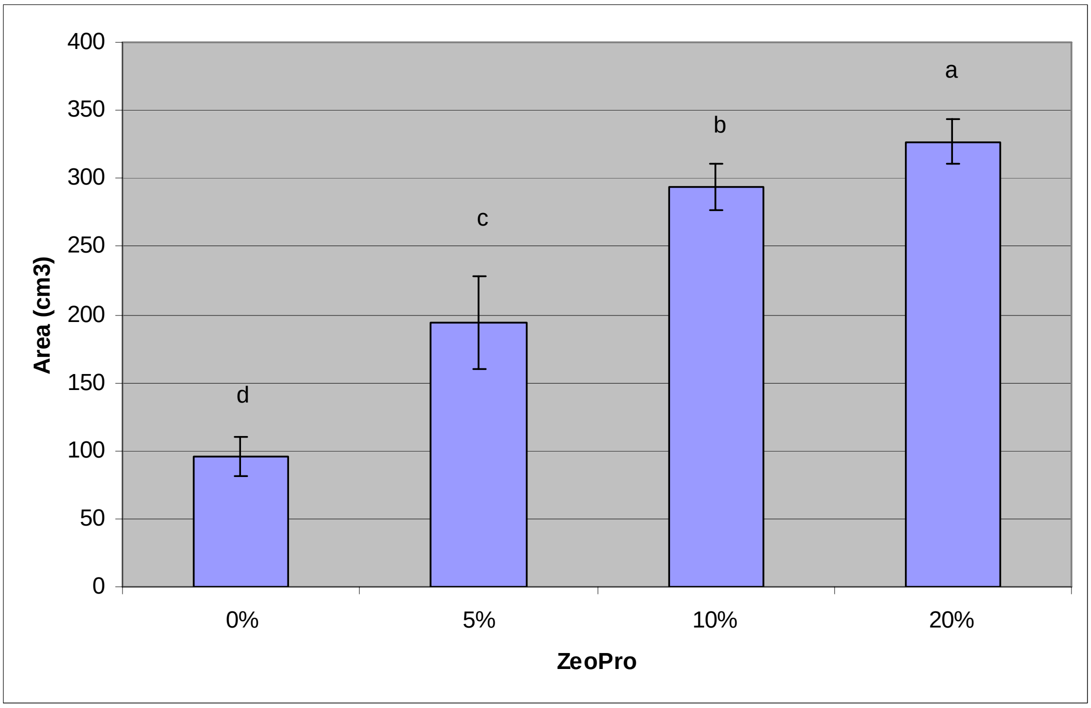

Fig 6. *Average total leaf area in cm^2 of 5 weeks old cucumber plants grown in a peat:sand mixture with the addition 0%, 5%, 10% and 20% ZeoPro (n=8).*

Summary of results

All the results for the cucumber plants indicate that the groups with 10% and 20% added ZeoPro have given the largest plants. The rate of development is faster and at the end of the trial the average fresh weight and dry weight is higher and the leaf area is larger. At all parameters, the values of the 20% group are consistently slightly higher than for the10%.

There is a small difference between the control group with no ZeoPro and the treatment with 5% added ZeoPro. 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. However, the difference is not as significant as between the 10% and 20% groups.

Tomato

General appearance

The tomato plants did not look healthy at the end of the trail. Especially the control group without ZeoPro (0%) was in very bad condition. They showed clear symptoms of phosphorous deficiency with stunted growth, thin and slender stems and dark greenish purple leaves coloured by anthocyanin. The other groups also showed some symptoms of phosphorous deficiency, with the lower side of the leaves marbled in purple (Taiz & Zeiger, 2002, Caspersen, 2006). These symptoms started to occur at the forth time of observation.

Increase of plant height

The development of the tomato plants in height is shown in fig. 7. The three groups treated with ZeoPro (5%, 10% and 20%) grow quit equally during the whole trial and ends up at heights between 100-120mm. At the last two observations the 5% group have the highest plants. The control group without ZeoPro grows slower during the whole trial and the final heights were in average just below 80mm.

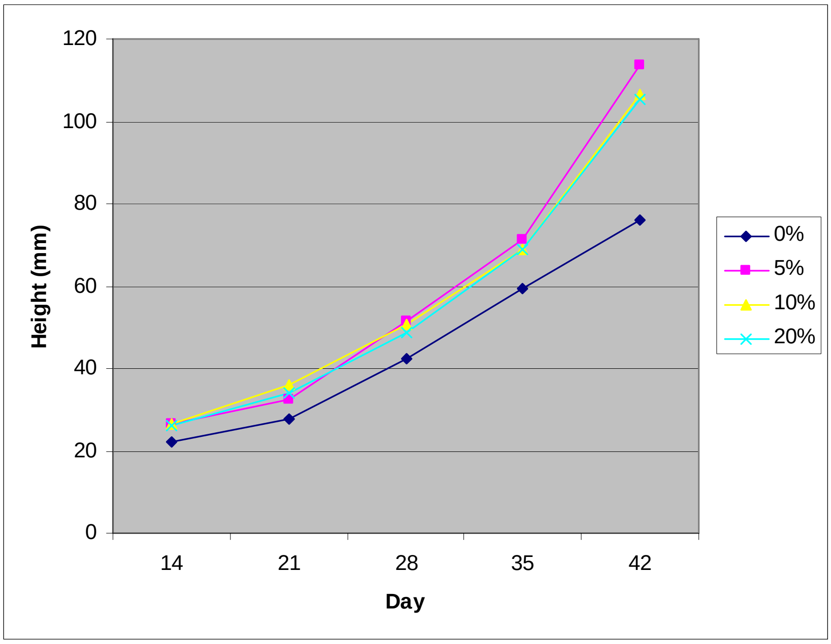

Fig 7. *Average height for tomato plants grown in a peat:sand mixture with the addition 0%, 5%, 10% and ZeoPro, measured once a week (n=8).*

Development of leaves

The average number of leaves per tomato plant, counted at four occasions during the trial, is shown in fig. 8. The 5% group has the most rapid development of leaves during the whole trial. At the end, these plants have in average 6-7 leaves. The 10% and 20% group develops very similar and ends up with 5-6 leaves. The 0% group has a clearly slower development and has only in average 4 leaves at the end of the trail.

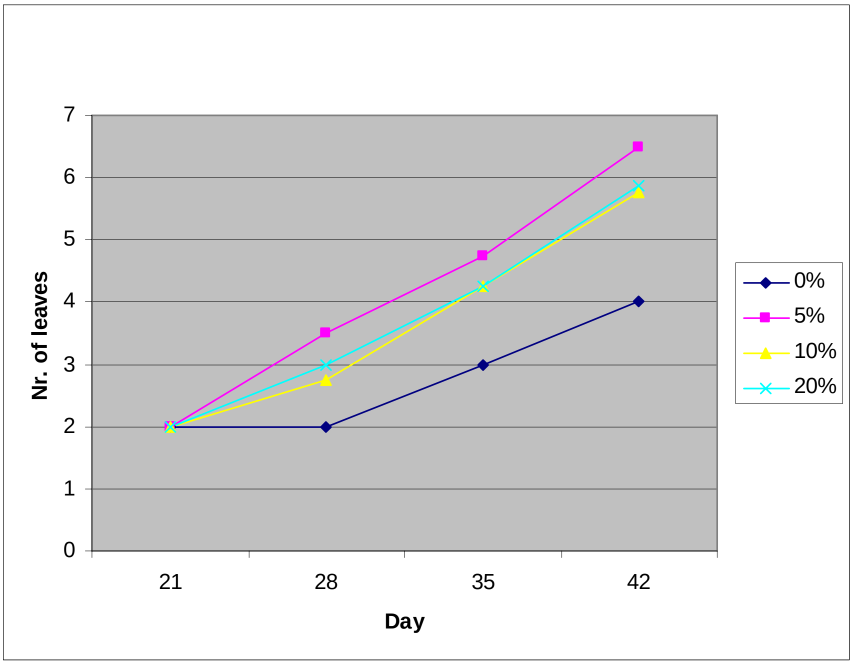

Fig 8. *Average number of leaves on tomato plants grown in a peat:sand mixture with the addition 0%; 5%, 10% and 20% ZeoPro, counted once a week (n=8).*

Final height

The final height of the tomato plants are presented in fig. 9. There is no significant difference between the 5%, 10% and 20% group which all end up at a height around 110 mm. The 0% group is clearly smaller with a height of approximately 75 mm.

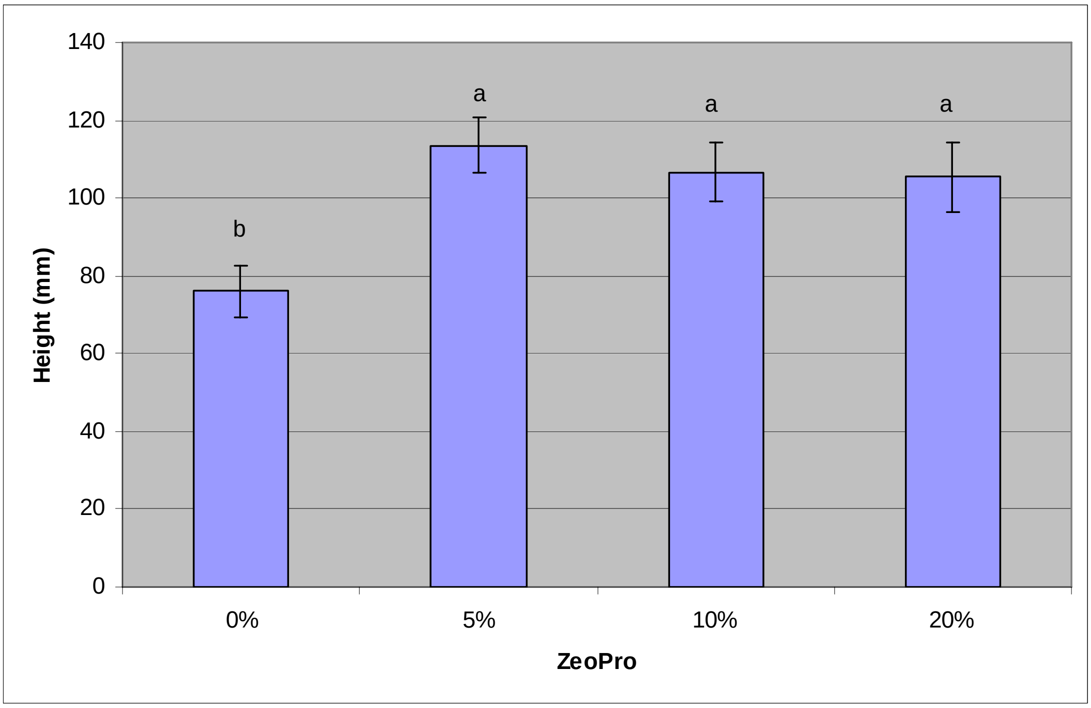

Fig 9. *Average height in mm of 6 weeks old tomato plants grown in a peat:sand mixture with the addition 0%, 5%, 10% and 20% ZeoPro (n=8).*

Fresh weight

The fresh weight of the tomato plants are presented in fig. 10. The highest fresh weights are found in the 5% group. They have an average weight of approximately 5 g. The 10% and 20% group follows just below and weighs about 4 g. The plants in the 0% group are clearly smaller than the other groups and all weighs less than 2 g.

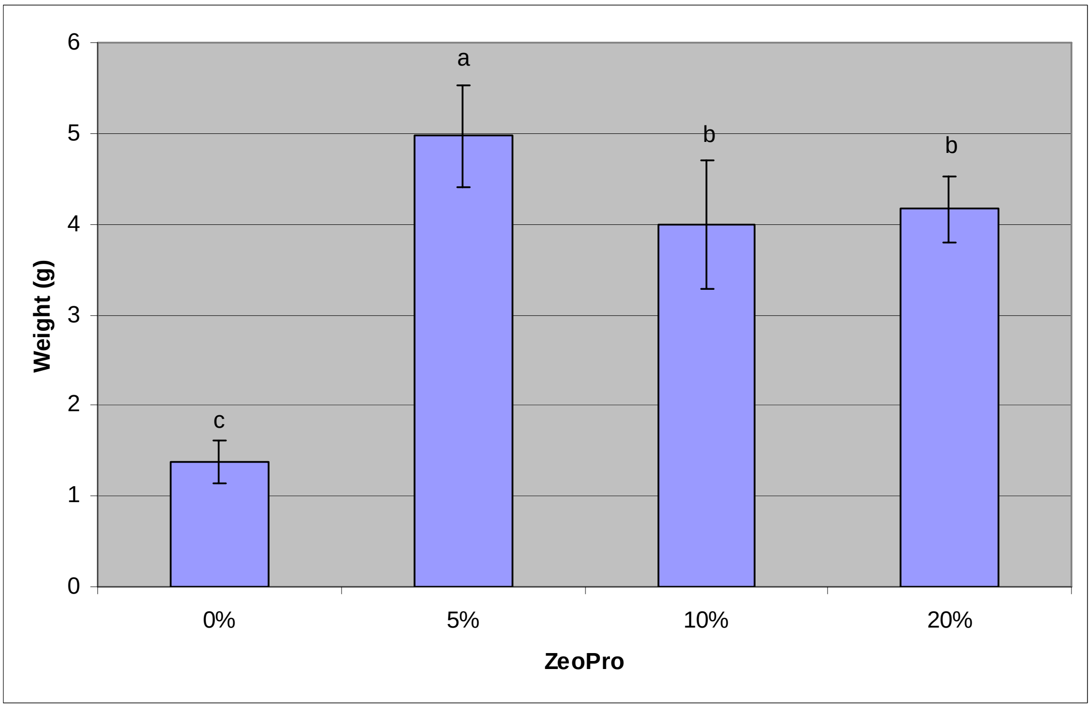

Fig 10. *Average fresh weight in g of 6 weeks old tomato plants grown in a peat:sand mixture with the addition 0%, 5%, 10% and 20% ZeoPro (n=8).*

Dry weight

The dry weight of the tomato plants are presented in fig. 11. The dry weights indicate the same as the fresh weights. The 5% group has the highest values and the 0% group clearly has the lowest values.

However, the result from this part may not be so reliable. The scale used only showed the weight with one decimal precision and the standard deviation lines shows that there was quit a large variation within each group.

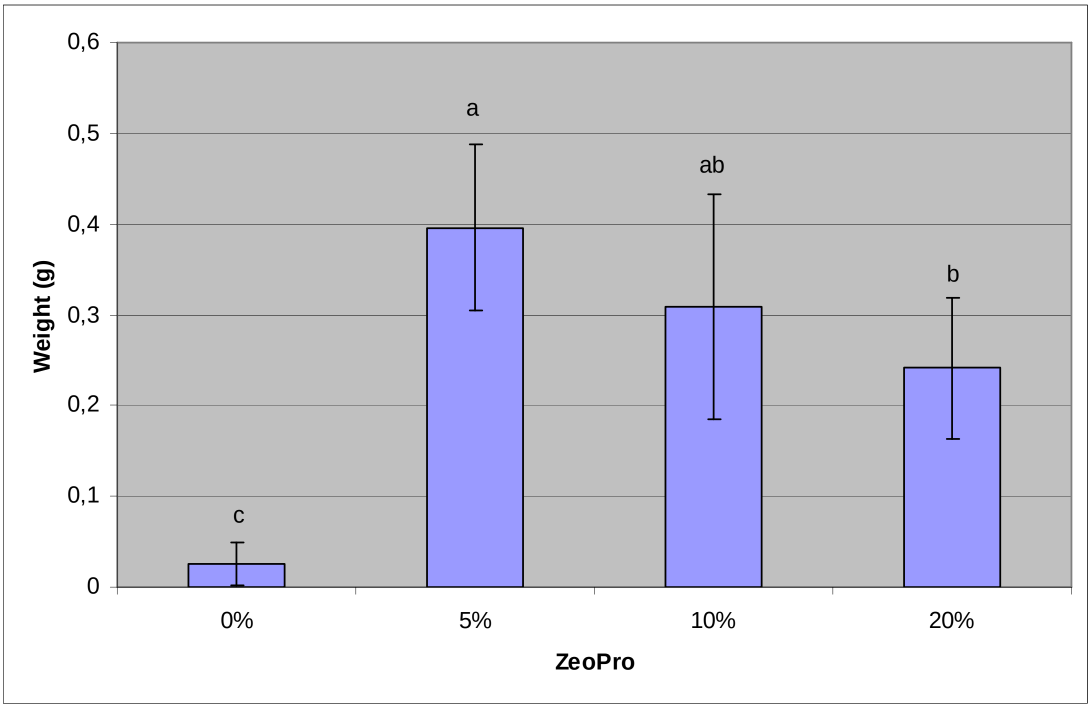

Fig 11. *Average dry weight in g of 6 weeks old tomato plants grown in a peat:sand mixture with the addition 0%, 5%, 10% and 20% ZeoPro (n=8).*

Leaf area

The leaf area of the tomato plants are presented in fig. 12. The pattern from the other measurements is supported also by the leaf area. The largest area is measured in the 5% group with about 150-200 cm^2. The 10% and 20% group follows just below with a leaf area of approximately 150 cm^2. The 0% group has a clearly smaller leaf area with only about 50 cm^2.

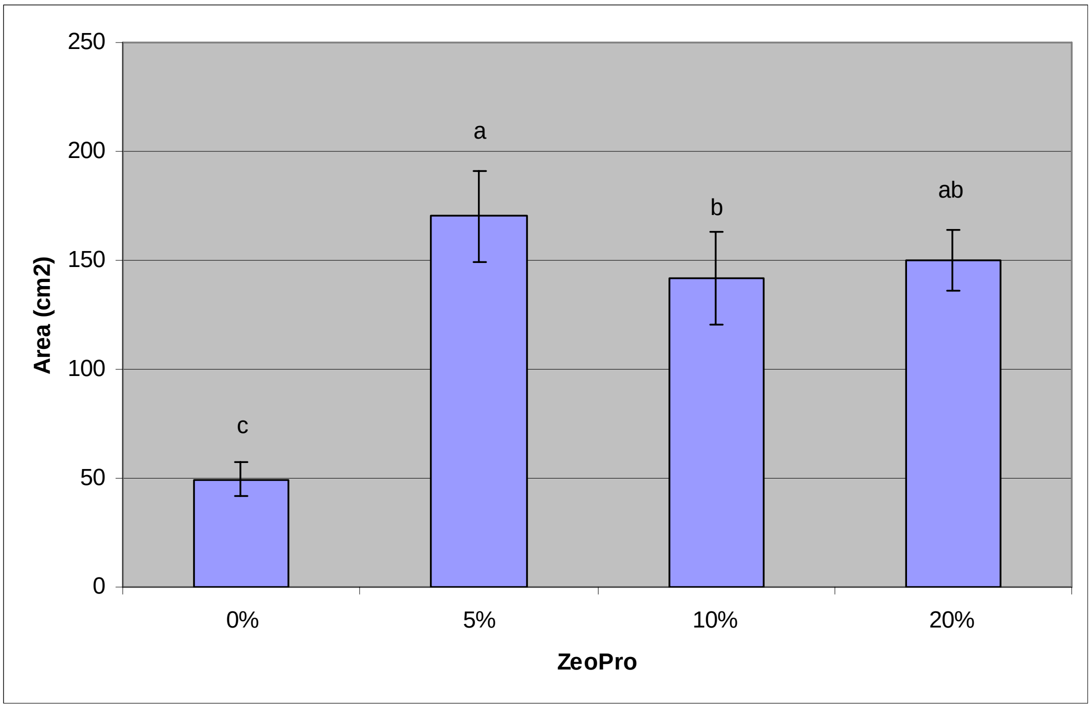

Fig 12. *Average leaf area in* cm^2 *of 6 weeks old tomato plants grown in a peat:sand mixture with the addition 0%, 5%, 10% and 20% ZeoPro (n=8).*

Summary of results

The results in total for the tomato plants show that 5% ZeoPro gives the largest plants. They have a faster development and get a higher fresh weight and dry weight and a larger leaf area. However, for some reason this group was observed to be moister than the others groups at two occasions (27 Feb. and 6 Mar.). The treatments with 10% and 20% ZeoPro are almost equal at all parameters and their values lie just below the means of the 5% group. The control group with no ZeoPro added is clearly slower in development and generates very small plants.

Discussion and Conclusion

Process of the project work

The aim of this bachelor project was to get a picture of zeolites and their application possibilities primarily in horticulture. The small study conducted was an attempt to investigate one of the commercial zeolite products, ZeoPro, claiming to benefit plant growing.

The design of the trial was not evident since only very few former studies done with this product was available. Several experiments with ZeoPro have been carried out in the U.S. for ZeoponiX in turf, floriculture and vegetable applications. However, the details of these experiments are considered proprietary. Also, a small Swedish investigation on the influence of ZeoPro on spruce and fur seedlings has been carried out. Hence the design of this trial was elaborated through discussions with my supervisor considering the available facts.

Some limitations of the project, primarily in terms of time able to spend, affected the design of the trial. The results had to be gained in only five weeks and therefore a fast growing crop hade to be chosen. Furthermore, the season (winter) required greenhouse cultivation.

For me, an important part of this project was the process of learning how to design and carry out an experiment. I had many valuable experiences during the work that I will be able to use in the future.

Discussion of results

The investigation of the effect of ZeoPro on cucumber and tomato plants showed some increase in growth when ZeoPro was added to the growth medium. In cucumber the growth increased with increasing amount of ZeoPro, generating the largest plants with 20% ZeoPro and the smallest in the control group without ZeoPro.

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 addition of ZeoPro were clearly smaller than the other groups.

These results indicate that ZeoPro has an effect on the growth of cucumber and tomato seedlings. The question is, why? The most important factor is probably that ZeoPro increased the supply of nutrients to the plants. ZeoPro is loaded with N-P-K 0,1-0,-0,6, which is a small amount but never the less can have an impact on the plants during this short culture (5 and 6 weeks).

ZeoPro's ability to retain moisture could also have effected the growth of the plants positively. ZeoPro might have prevented water to drain out from the pots and thereby giving the plants access to more moisture for a longer time.

The structure of the substrate was also altered by the addition of ZeoPro. It might have improved the aeration and created a better structure which could enhance root growth and benefit the plant. However, the growth of the roots were not evaluated in this trial.

ZeoPro has in some cases been claimed to increase germination rates. That could not be observed in this trial. Larger groups would be necessary to be able to distinguish a pattern. Furthermore, genetic variation in the seeds and other external factors could contribute to uneven germination.

There are also many error sources to consider when interpreting the results. First of all, the water supply might have been uneven. All pots were watered thoroughly at the beginning of the trial. However, the amount of water added was not measured and could have differed between the pots. This may have given the plants different prerequisites during the first weeks. For a short period during the trial a leaching high pressure nozzle in the ceiling of the greenhouse might have affected the moisture in some of the pots.

As mentioned in the summary of the tomato results, the 5% group was observed to be moister than the others groups at the third and fourth observation (27 Feb. and 6 Mar.). The reason for this can not be easily explained as it was not positioned below the leaching nozzle. The initial water supply might have been larger in this group which could have affected the moisture content in a later stage.

Some small errors were also made when measuring the different parameters. First of all, the results of the dry weight may not be so reliable. The scale used, only showed the weight with one decimal precision and the standard deviation lines indicate that there was quit a large variation within each group. Also the measurements of height can have small errors as it was carried out with a ruler.

Another aspect to consider is that the pots were not randomly distributed on the bench. Each treatment was placed on a tray and the trays were then put beside each other on the bench. This can create different microclimatic conditions among the pots which can effect the plant growth. However, considering the small surfaces used in this trial, microclimatic differences are negligible. In a future study it would be appropriate to mix the pots from the different treatments on the bench to be able to exclude differences in growth due to this kind of external factors. It can be carried out by a random mix distribution or a block design experiment.

In the experiments conducted for ZeoponiX, several results indicate that cultivation in zeoponic substrates can achieve the same quality of plants as conventionally produced plants fertilized with nutrient solution. Those results can not be supported by my study. None of the treatments produced plants with a “standard” quality and all the plants seemed to suffer from nutrient deficiency. To be able to evaluate this in a better way, a fourth treatment, with some kind of fertilization, could have been included in the trial. That would have made it possible to compare the effect of ZeoPro to another nutrient source. As the group with no added ZeoPro generated plants with a very poor quality they were perhaps not the best to use as control.

Furthermore, ZeoPro is claimed to act as slow-release fertilizer in a process combining dissolution and ion exchange reactions. However, the long-term effect of a slow-release fertilizer could not be explored in this short trial. A longer culture would be needed to investigate that kind of processes. My study just presents an indication of the effect of ZeoPro.

It is also hard to draw any conclusions about optimal ZeoPro content from this small pre study. The cucumber seedlings seem to respond with increasing growth with increased content of ZeoPro. The tomato seedlings on the other hand show the best results in the group with 5% ZeoPro. However, this was probably due to excess water supply rather than a response to the ZeoPro content. The content of ZeoPro recommended by ZeoponiX for potted vegetables is 5%-10% (ZeoponiX, 2000)

Future aspects

From my literature study I can conclude that zeolites have a large potential in many areas of application including the horticultural sector. However, there are many aspects to be taken in consideration when developing new products for the future. Physical and chemical properties vary a lot between different types of zeolites and the appropriate mineral for each purpose has to be chosen.

There will be need for lots of further studies trying to find the best application possibilities for ZeoPro in horticultural production. Based on the experiences from my small trial some suggestion for future approaches will be presented.

First of all, longer growing periods are necessary to be studied to be able to draw any reliable conclusions. When it comes to vegetable crops a high yield is the major aim and it is not automatically connected to increased growth. Hence, the yield would be the best measurement of ZeoPro's effectiveness. Crops with longer cultural programmes are also needed to be able to see effect of ZeoPro as a slow-release fertilizer and be able to decide the optimum concentration of ZeoPro in the substrate.

Furthermore, the design of an experiment can be altered in many ways. As mentioned before, treatments comparing conventional fertilization and the effect of ZeoPro would be interesting to look further into. An experiment combining two factors, amount of ZeoPro and fertilization, could be carried out. The interaction between treatment and fertilizer would then be investigated.

The subject of suitable substrate to mix ZeoPro with is another area which has not been explored. In this trial and most of the other studies conducted, peat has been the main substrate. Nevertheless, it would be interesting to examine other possibilities like for example pumice stone or perlite.

To gain more knowledge about nutrient uptake, the level of nutrition in the plants could be analysed at several occasions during a trial. However, since plants have to be destroyed in order to carry out these analyses you loose the advantage of following the same plant during the whole trail.

A great benefit in the future would be if ZeoPro can decrease leakage of nutrients to the environment, which is a big problem both in field production and in greenhouse production systems today. Zeolites are known to help retain the nutrients in the root zone. The use of ZeoPro might lead to more effective use of fertilizers by reducing the rates for the same yield, by prolonging their activity and finally by producing higher yields.

The economical aspects also have to be considered when evaluating the future utilisation of ZeoPro. What can you gain from using this product? Is the increased production enough to cover the cost of ZeoPro? It would probably be more profitable crops with longer cultural programmes where the benefits of ZeoPro can be fully harnessed.

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Appendix 1

Development of cucumber plants

Height (mm) and Number of leaves

	20-feb		**27-feb**		**06-mar**		**13-mar**	
	height	leaves	height	leaves	height	leaves	height	leaves
C01	46		50	1	70	1	73	2
C02	48		70	1	93	2	99	2
C03	57		86	1	100	2	115	3
C04	56		80	1	99	2	112	3
C05	56		79	1	108	2	108	3
C06	57		71	1	89	2	91	3
C07	67	1	87	2	107	3	124	4
C08	62		90	1	111	2	115	3
Mean	56,125	1	76,625	1,125	97,125	2	104,625	2,875
C51	63		80	1	111	3	131	4
C52	42		53	1	81	2	118	4
C53	38		56	1	95	2	114	3
C54	52		73	1	107	2	123	4
C55	30		36	1	72	2	100	3
C56	42		52	1	76	2	104	4
C57	50		65	1	104	3	120	4
C58	49		70	1	108	2	132	4
Mean	45,75		60,625	1	94,25	2,25	117,75	3,75
C101	55		94	2	122	3	165	4
C102	55		86	2	121	3	161	4
C103	63		94	1	127	3	170	4
C104	52		76	2	115	3	167	4
C105	72		111	2	131	3	168	4
C106	63		96	2	132	3	161	4
C107	65		115	2	142	3	186	4
C108	73		107	2	138	3	163	4
Mean	62,25		97,375	1,875	128,5	3	167,625	4
C201	72		126	2	160	3	190	4
C202	72		110	2	147	3	203	4
C203	76		101	2	151	3	190	4
C204	62		106	2	133	3	190	4
C205	62		114	2	150	3	211	4
C206	67		119	2	159	3	205	4
C207	61		100	2	149	3	206	4
C208	75		124	2	159	3	202	4
Mean	68,375		112,5	2	151	3	199,625	4

Appendix 2

Development of tomato plants

Height (mm) and Number of leaves

	20-feb	**27-feb**		**06-mar**		**13-mar**		**20-mar**	
	height	height	leaves	height	leaves	height	leaves	height	leaves
T01	20	27	2	39	2	56	3	70	4
T02	26	32	2	44	2	62	3	78	4
T03	28	31	2	45	2	62	3	74	4
T04	23	25	2	45	2	60	3	83	4
T05	17	25	2	38	2	57	3	68	4
T06	18	25	2	38	2	55	3	70	4
T07	24	27	2	49	2	63	3	78	4
T08	22	30	2	42	2	60	3	87	4
Mean	22,25	27,75	2	42,5	2	59,375	3	76	4
T51	23	32	2	59	4	77	5	107	7
T52	30	34	2	58	3	69	5	120	6
T53	31	35	2	59	4	77	5	111	7
T54	23	29	2	46	4	66	5	120	7
T55	27	33	2	51	4	70	5	119	7
T56	29	35	2	46	3	72	4	108	6
T57	28	31	2	47	3	76	5	120	6
T58	22	31	2	46	3	64	4	103	6
Mean	26,625	32,5	2	51,5	3,5	71,375	4,75	113,5	6,5
T101	28	36	2	57	3	76	4	104	6
T102	25	34	2	51	3	67	4	112	6
T103	24	34	2	45	2	66	4	109	5
T104	24	35	2	52	3	65	4	99	6
T105	34	45	2	61	4	75	5	108	6
T106	30	40	2	56	3	81	5	119	6
T107	20	29	2	39	2	56	4	94	5
T108	28	35	2	46	2	65	4	108	6
Mean	26,625	36	2	50,875	2,75	68,875	4,25	106,625	5,75
T201	20	30	2	42	3	65	4	89	5
T202	24	32	2	52	3	70	4	111	6
T203	31	38	2	54	3	69	5	101	6
T204	30	36	2	48	3	75	5	115	6
T205	28	37	2	50	3	70	4	114	6
T206	30	38	2	50	3	75	4	110	6
T207	27	34	2	51	3	64	4	103	6
T208	18	26	2	42	3	62	4	100	6
Mean	26	33,875	2	48,625	3	68,75	4,25	105,375	5,875

Appendix 3

Final observations for cucumber

13-mar

	fresh weight (g)	**dry weight (g)**	**leaf area (cm2)**
C01	2,1	0,05	67,2
C02	2,9	0,13	93
C03	3,3	0,3	105,3
C04	3,2	0,25	105,3
C05	3,2	0,2	99,7
C06	2,6	0,13	84,4
C07	3,4	0,27	110,6
C08	3,2	0,23	104,6
Mean	2,9875	0,195	96,2625

C51	6,6	0,5	231,7
C52	5,4	0,23	197,7
C53	5,3	0,29	195,6
C54	5,3	0,27	187,4
C55	4,2	0,2	142,8
C56	4,4	0,21	147,2
C57	6,1	0,49	221
C58	6,6	0,49	230,2
Mean	5,4875	0,335	194,2

C101	9	0,7	298,1
C102	9,7	0,69	321,3
C103	9,3	0,68	308,7
C104	8,3	0,45	276,2
C105	9	0,78	297
C106	9,1	0,75	289,9
C107	9,1	0,74	270,6
C108	9,3	0,85	287,5
Mean	9,1	0,705	293,6625

C201	9,8	0,7	330,3
C202	9,8	0,64	331,1
C203	9,7	0,83	331
C204	9,6	0,75	316,2
C205	9,7	0,55	300,5
C206	10,2	0,6	323,1
C207	10,4	0,69	324,1
C208	11,8	0,91	360,4
Mean	10,125	0,70875	327,0875

Appendix 4

Final observations for tomato

20-mar

	fresh weight (g)	dry weight (g)	leaf area (cm2)
T01	1,1	0,01	41,9
T02	1,6	0,03	56,7
T03	1,7	0,05	61,7
T04	1,6	0,07	56,5
T05	1,1	0,01	39,5
T06	1,2	0,01	45,5
T07	1,3	0,01	44,6
T08	1,4	0,01	50,2
Mean	1,375	0,025	49,575
T51	4,9	0,37	178,2
T52	5,3	0,36	178,9
T53	5,7	0,56	197,3
T54	5	0,33	176,1
T55	5,5	0,5	188,5
T56	4,9	0,32	157
T57	4,6	0,42	154,4
T58	3,9	0,31	132,4
Mean	4,975	0,39625	170,35
T101	4,4	0,37	162
T102	4,3	0,37	154,6
T103	4	0,3	140,9
T104	3,7	0,27	132,4
T105	3,9	0,35	141,1
T106	5,2	0,51	168,3
T107	2,7	0,09	99,7
T108	3,8	0,21	134,1
Mean	4	0,30875	141,6375
T201	3,7	0,23	131,2
T202	4,3	0,32	157,4
T203	4,5	0,38	163,9
T204	4,7	0,24	169,9
T205	4	0,16	145,4
T206	4,3	0,24	153,9
T207	4,1	0,22	141,4
T208	3,7	0,14	135,9
Mean	4,1625	0,24125	149,875