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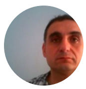

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Comparison of the use of zeolite and perlite as substrate for crisp-head lettuce

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Abstract

This research was carried out to assess the effects of zeolite and perlite on growth and nutrient status of lettuce plants and the amount of waste elements. The trials were done in a PE covered tunnel during autumn and spring seasons. Plant material was *Lactuca sativa* var. *capitata*, and the cultivars Bombola and Brogan were used for autumn and spring seasons, respectively. Five different growing media based on perlite and clinoptilolite, a kind of zeolite, mixed at different ratios (1 + 0, 3 + 1, 1 + 1, 1 + 3, 0 + 1, v/v) were tested. It was concluded that the use of zeolite led to increased plant growth, higher N and K contents in plant tissues and to reduced K leaching.

Keywords: Soilless culture; Substrates; Clinoptilolite; Perlite; Plant growth; Nutrient uptake; Leaching

1. Introduction

Accumulation of pests and diseases in soil has always been a problem in protected cultivation. Production is maintained by practising soil sterilisation. Steam sterilisation in some cases is not economically viable and the use of methyl bromide, which is the most common soil fumigant, is banned in many states and will be phased out by 2005 in industrialised countries under the Montreal Protocol. One of the alternatives is soilless cultivation (Burrage, 1999; Van Os, 2000).

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There are three main types of soilless cultivation: buffering substrates (e.g. peaty substrates), inert substrates (e.g. rockwool) and no substrates (e.g. NFT). Although NFT is used commercially, it is reported that it possesses certain risks, e.g. spreading of diseases, and lack of buffering capacity for mistakes in mismanagement. On the other hand, substrate culture is gaining more importance year-by-year all over the world. Substrates used differ according to the countries, for example rockwool is common in Northwest Europe, whereas perlite and locally mined pumice are used a lot in Southern Europe (Van Os, 2000).

Turkey has nearly 30 000 ha greenhouse area, of which 96% is used for vegetable growing. Production is mainly realised in soil. Soilless cultivation is being practised on a commercial basis only on 75 ha, but it is evident that it will increase if the upcoming phase-out of methyl bromide is taken into account. Growers prefer to use local substrates such as perlite or pumice mixed with coir, which is imported, particularly to increase the buffering capacity. On the other hand, Turkey has rich mineable deposits of zeolites with attractive physical and chemical properties for agriculture (Yucel, 1987). Zeolites are hydrated aluminium–silicate minerals in which Al and Si tetrahedra are connected by shared oxygen atoms to form a three-dimensional framework structure. They are characterised by high ability to lose and gain water and to exchange cations without a major change of structure (Mumpton, 1999; Kithome et al., 1999). The structure of zeolites generates particular properties of adsorption and ion-exchange, which makes them potentially useful in the field of hydroponic crop production (Harland et al., 1999). Of more than 40 natural zeolite species, clinoptilolite seems to be the most abundant zeolite in soils and sediments (Ming and Dixon, 1987). It has a relatively high ion-exchange capacity with a preference for large cations such as NH_4^+ and K^+ (Harland et al., 1999).

There are several studies on possibilities of using clinoptilolite as a substrate, and it is reported that clinoptilolite led to increases in yield (Baikova and Semekhina, 1996; Loboda, 1999), decreases in the demand of fertilizers (Loboda, 1999) and reduction in the leaching of NO_3-N (Pivert et al., 1997; Harland et al., 1999) and K (Pivert et al., 1997; Oztan, 2002).

The objective of this investigation was to assess the effects of clinoptilolite compared to perlite on plant growth, uptake of nutrients, and waste amounts of NO_3, P, K, Ca and Na.

2. Materials and methods

The trials were done in a PE covered high tunnel during autumn season in 2001 and spring season in 2002. Plant material was *Lactuca sativa* var. *capitata*, the cultivars Bombola and Brogan were used for autumn and spring cultivation seasons, respectively. Seedlings were produced in a mixture of peat and perlite (3 + 1, v/v). The sowing and planting dates were 17 September and 12 October in the first experiment (2001), 15 March and 15 April in the second experiment (2002).

Five different growing media: (1) perlite, (2) 3 + 1 (v/v) perlite + zeolite, (3) 1 + 1 (v/v) perlite + zeolite, (4) 1 + 3 (v/v) perlite + zeolite and (5) zeolite were tested. The experimental design was randomised blocks with three replicates and 18 plants in each plot.

Natural zeolite mined in Gördes by Enli Madencilik Inc. in Turkey was used. According to the results of mineral identification using X-ray diffraction technique, it consists of mainly clinoptilolite and traces of feldspars and quartz. Its cation exchange capacity was between 0.95 and 1.40 $mmol_c\ g^{-1}$. Particle sizes of zeolites used in the trial varied between 1.8 and 3.5 mm. Eti Holding Inc. in Turkey supplied the horticultural grade (more than 60% of particles sized between 2 and 5 mm) perlite used in the study.

Water and nutrient requirements of the plants were supplied through a complete nutrient solution, applied with a drip irrigation system. The chemical composition of the nutrient solution was as follows ($mg\ L^{-1}$): N: 150, P: 50, K: 150, Mg: 50, Ca: 150, Fe: 5; Mn: 0.5, Cu: 0.03, Zn: 0.05 (Resh, 1991).

In autumn production, plants were harvested on 20 and 26 December 2001 and 2 January 2002 selectively according to the growth of the plants. In spring season, all plants were harvested at the same time (27 May 2002). The following parameters were measured; head mass, number of leaves, leaf nutrient contents, and the chemical content and volume of drained out solution.

The head mass and number of leaves were determined immediately after harvesting. In order to determine the nutrient content of the leaves, the whole plants were pulled up from the growing media four times at 2 weeks interval in autumn and three times at weekly intervals in spring starting one month after planting. Total N was measured by modified Kjeldahl method; the other elements were measured using the wet digested extracts by colorimeter for P, flame photometer for K and Ca, by atomic absorption spectrophotometer for Mg, Fe, Cu, Zn and Mn (Kacar, 1972). The amounts of nutrient uptake were calculated from the nutrient contents of the plants pulled up at the end of the growing seasons.

The volume of drained out solution was recorded. Concentrations of NO_3, P, K, Ca and Na in samples taken at 2 weeks interval were determined spectrophotometrically for NO_3 (Fresenius et al., 1988), colorimetrically for P, and flame photometrically for K, Ca and Na (Kacar, 1972). Waste amounts of the elements were calculated from the data of volume and elemental composition of drained out solution.

The collected data were analysed by analysis of variance, and treatments were compared with LSD and orthogonal comparisons.

3. Results

3.1. Plant growth

In autumn, differences between tested substrates in respect to head mass and marketable head mass were found to be statistically significant ($p < 0.01$) for pure zeolite and perlite. Zeolite resulted in higher head mass compared to perlite. The number of leaves forming the head also changed according to media, and differences were significant at 1% level for 100 % zeolite and perlite, whereas differences in respect to number of the outer leaves were not significant. The lowest values related to number of leaves forming the head were obtained from perlite. Number of non-consumable leaves per plant ranged from 2.1 to 2.9 between the substrates and the differences were not significant (Table 1).

Table 1
Plant growth characteristics in autumn

Substrate	Head mass (g)	Marketable head mass (g)	No. of leaves forming head	No. of outer leaves	No. of non-consumable leaves
Perlite	447.8 b	433.0 b	15.3 b	7.3	2.4
3 + 1 p:z	522.8 ab	510.3 ab	18.1 ab	6.3	2.1
1 + 1 p:z	565.9 a	548.5 a	19.5 a	6.0	2.7
1 + 3 p:z	513.2 ab	491.6 ab	19.3 a	5.7	2.9
Zeolite	568.2 a	535.8 a	18.6 ab	7.3	2.1
LSD 5%	93.8	78.5	3.3	n.s.	n.s.

Table 2
Plant growth characteristics in spring

Substrate	Head mass (g)	Marketable head mass (g)	No. of leaves forming head	No. of outer leaves	No. of non-consumable leaves
Perlite	564.0	549.7	17.1	6.0	2.3
3 + 1 p:z	570.1	553.1	20.5	5.0	1.9
1 + 1 p:z	568.9	553.9	18.8	4.5	2.2
1 + 3 p:z	657.0	632.6	25.0	4.8	1.9
Zeolite	683.7	663.3	23.0	6.5	1.6
LSD 5%	n.s.	n.s.	n.s.	n.s.	n.s.

In spring, no significant differences between the substrates in respect to head mass, marketable head mass and number of leaves could be found using variance analysis (Table 2). However, orthogonal comparisons showed that head mass and marketable head mass increased linearly by increasing ratios of zeolite in growing medium.

3.2. Plant nutrient status

The nutrient contents of leaves are presented in Tables 3 and 4. In autumn season, statistically significant differences between substrates were determined with respect to N, K and Cu. N contents of the plants grown in zeolite and mixture of perlite + zeolite (1 + 1) were higher. Mixing zeolite into the growing medium resulted in increased K content of the plants. Regarding the Zn content, differences between substrates were not statistically significant according to the results of variance analysis. However, orthogonal comparisons showed that Zn content of plant tissues increased linearly by increasing amounts of zeolite in the growing medium.

In spring season, zeolite and mixtures with zeolite gave higher contents of N and K as compared to perlite, whereas perlite resulted in higher Ca and Mg contents in plant tissues compared to the zeolite medium (Table 4).

The amounts of nutrient uptake are given in Tables 5 and 6. In autumn season; higher uptake levels of K, Fe and Zn were detected in zeolite-containing media than pure perlite, whereas Mg uptake was higher in pure perlite. The effect of zeolite on increasing the nutrient uptake of plants was more obvious in the spring season.

Table 3
Average nutrient contents of plants grown in autumn

Substrate	%					mg kg^{-1}			
	N	P	K	Ca	Mg	Fe	Cu	Zn	Mn
Perlite	3.78 ab	0.69	5.31 c	1.27	0.48	184	126 ab	39.5	61.2
3 + 1 p:z	3.71 b	0.71	6.09 b	1.21	0.41	210	99 bc	46.6	56.6
1 + 1 p:z	3.92 a	0.67	6.67 ab	1.38	0.39	246	64 d	47.9	74.8
1 + 3 p:z	3.71 b	0.84	6.72 ab	1.23	0.40	223	142 a	49.4	63.0
Zeolite	3.88 a	0.74	6.90 a	1.40	0.37	224	83 cd	54.3	67.3
LSD 5%	0.15	n.s.	0.71	n.s.	n.s.	n.s.	34	n.s.	n.s.

Table 4
Average nutrient contents of plants grown in spring

Substrate	%					mg kg^{-1}			
	N	P	K	Ca	Mg	Fe	Cu	Zn	Mn
Perlite	2.90 b	0.82	6.98 c	1.33 a	0.45 a	211	15.9	61.5	54.2
3 + 1 p:z	3.44 a	0.86	8.78 ab	1.19 ab	0.42 ab	220	16.2	63.8	68.0
1 + 1 p:z	3.31 a	0.82	9.47 a	1.30 a	0.46 a	220	12.9	75.2	66.1
1 + 3 p:z	3.42 a	0.89	7.81 bc	0.97 c	0.34 c	199	10.6	74.4	66.0
Zeolite	3.37 a	0.82	8.95 ab	1.11 bc	0.37 bc	219	11.7	71.5	67.9
LSD 5%	0.30	n.s.	1.41	0.18	0.07	n.s.	n.s.	n.s.	n.s.

Table 5
Nutrient uptake in autumn (mg plant^{-1})

Substrate	N	P	K	Ca	Mg	Fe	Cu	Zn	Mn
Perlite	639	122	986	360	104	3.803	1.746	0.637	2.326
3 + 1 p:z	479	104	1030	242	59	3.471	0.715	0.591	1.568
1 + 1 p:z	746	148	1194	334	84	4.360	0.806	0.888	1.224
1 + 3 p:z	783	187	1583	376	89	5.461	1.014	0.739	1.952
Zeolite	626	131	1194	342	70	4.914	0.639	1.062	1.683

Table 6
Nutrient uptake in spring (mg plant^{-1})

Substrate	N	P	K	Ca	Mg	Fe	Cu	Zn	Mn
Perlite	456	161	1382	152	66	3.209	0.108	1.144	0.610
3 + 1 p:z	494	189	1576	129	62	2.864	0.126	1.236	0.883
1 + 1 p:z	362	160	1525	142	71	2.831	0.122	1.291	0.760
1 + 3 p:z	851	209	1823	146	58	5.074	0.190	2.554	1.302
Zeolite	902	238	2127	174	72	5.117	0.198	1.658	1.319

3.3. Chemical content of drained out solution

Elemental composition of drained out solution and amounts of discharged elements in autumn season are given in Table 7. Analysis of variance showed significant differences between substrates at 1% level with respect to P, K, Ca and Na content in autumn season.

Zeolite addition decreased leaching of K, whereas it increased Ca and Na concentrations in drained water.

In spring season, nutrient concentration in the drained out solution and amounts of waste elements changed according to substrate as given in Table 8. Zeolite addition decreased K leaching, in contrast to increased Na concentration in drained out solution.

Table 7
Elemental composition of drained solution and amounts of waste elements in autumn

Substrate	Element contents (mg l^{-1})					Waste elements (mg $plant^{-1}$)				
	NO_3	P	K	Ca	Na	NO_3	P	K	Ca	Na
Perlite	192.8	16.0ab	107.0a	145.5b	36.2b	1259	104	698	950	236
3 + 1 p:z	189.5	16.4a	44.5b	171.5a	55.8a	1352	117	318	1224	398
1 + 1 p:z	168.7	11.3bc	34.8b	172.5a	62.8a	1221	82	252	1249	455
1 + 3 p:z	161.6	10.6c	40.2b	167.5a	58.8a	1186	78	295	1229	432
Zeolite	163.4	14.0abc	35.5b	178.0a	63.2a	1384	119	301	1507	535
LSD 5%	n.s.	4.8	11.6	11.9	8.1					

Table 8
Elemental composition of drained solution and amounts of waste elements in spring

Substrate	Element contents (mg l^{-1})					Waste elements (mg $plant^{-1}$)				
	NO_3	P	K	Ca	Na	NO_3	P	K	Ca	Na
Perlite	218.5	17.7	112.0 a	182	36.3 d	1715	139	879	1428	285
3 + 1 p:z	230.7	18.1	69.3 b	190	49.3 c	1708	134	513	1407	365
1 + 1 p:z	234.8	15.2	58.6 c	183	58.7 b	2043	132	510	1593	511
1 + 3 p:z	214.0	14.6	49.3 d	188	62.0 b	1560	106	359	1371	452
Zeolite	224.6	15.3	51.7 cd	185	77.0 a	1655	115	387	1385	576
LSD 5%	n.s.	n.s.	8.76	n.s.	3.49					

4. Discussion

The trial showed that zeolite increased head mass compared to perlite. These results are in accordance with the findings of Loboda (1999) concluding that zeolite increased yield in pepper. Also, Harland et al. (1999) reported that yields of pepper plants grown in zeolite were as good as or better than those in rockwool. On the other hand, Maloupa and Gerasopoulos (1999) comparing perlite and zeolite for gerbera cultivation report that the use of perlite leads to a higher yield than zeolite. This contradiction may have resulted from differences between experimental conditions such as fertigation.

Winsor and Adams (1987) mention that optimum ranges of nutrients in lettuce leaves change as follows: 3.5–5.5% N, 0.5–0.8 % P, 5–10% K, 1–1.8% Ca, 5–15 mg kg^{-1} Cu, 50–200 mg kg^{-1} Mn. On the other hand, Hakerlerler et al. (1992) report that the leaf contents of N, P, K, Ca, Mg, Fe, Zn, Mn and Cu for lettuce plants should be above 4.0, 0.4, 4.2, 0.88 and 0.25%, and 55.9, 30, 22 and 5 mg kg^{-1}, respectively in order to be considered adequate. If our results are compared with the above-mentioned references, it can be said that essential elements excluding N in spring season were found within adequate ranges in leaf tissues in both seasons. Although the N content of the leaves was found to be lower than the normal range in the spring season, it was above the critical level for nitrogen deficiency for lettuce plants (1.5%) grown under high light conditions (Winsor and Adams, 1987).

Plant tissue analyses revealed that the use of zeolite led to higher N and K contents in comparison to perlite. These results support the previous report of Harland et al. (1999) submitting that zeolite acts as a reservoir, holding elements in its structure for slow release to the substrate solution or directly to plant roots. Challinor et al. (1995) report that clinoptilolite is highly selective for potassium and ammonium nitrogen.

In both seasons, it was determined that zeolite reduced K leaching, in contrast to increased Na concentration in drained out solution. These results are in accordance with the findings of previous studies reporting that zeolite or zeolite-containing media decreased K concentration (Pivert et al., 1997; Oztan, 2002) and increased Na concentration (Pivert et al., 1997; Harland et al., 1999) in drained solution. Although there are some studies reporting that zeolite had a decreasing effect on nitrate leaching (Pivert et al., 1997; Harland et al., 1999), our results do not support these findings.

The results showed that zeolite has advantages as a substrate compared to perlite, as it increased growth of crisp-head lettuces. This effect may be attributed to increase in the uptake of some nutrients since zeolite has high cation exchange properties, and acts as a reservoir, holding elements in its structure for slow release to the rhizosphere. Our results related to element leaching are in accordance with the results of nutrient uptake.

5. Conclusion

In soilless culture, discharging waste nutrient solutions and substrates cause environmental pollution. Benoit and Ceustermans (1995) report that 1 ha of soilless tomato culture on average causes the following amounts of waste: 60 m^3 of rockwool mats, 12 m^3 of rockwool pots, 2000 m^3 nutrient solution (at 20% overdrain), 5 t of plastics for mat wrapping, soil cover, etc. With the increasing awareness of the environmental aspects during the late eighties and early nineties, sustainable soilless systems with a more efficient use of water and fertilisers and lower costs because of the savings, a reduction of the amount of waste material, less pollution of ground and surface water, have gained importance (Van Os, 2000). Our results indicated that zeolite could provide economy in nutrient usage and reduce environmental pollution by decreasing the amount of leaching elements. In addition to these, after soilless cultivation zeolite can be used as soil conditioner in open field and thereby also reduces the amount of waste material. As a conclusion, zeolite can be used for optimisation of the root environment in soilless culture by promoting efficient nutrient uptake which in turn reduces environmental pollution. Further research is needed to assess the interaction between zeolite and nutrient levels for different crops and different soilless cultivation techniques, e.g. open or closed system.

References

Baikova, S.N., Semekhina, V.M., 1996. Effectiveness of natural zeolite. Kartofel Ovoshchi 3, 41–42.

Benoit, F., Ceustermans, N., 1995. Horticultural aspects of ecological soilless growing methods. Acta Hort. 396, 11–24.

Burrage, S.W., 1999. The nutrient film technique (NFT) for crop production in the mediterranean region. Acta Hort. 491, 301–306.

Challinor, P.F., Le Pivert, J.M., Fuller, M.P., 1995. The production of standard carnations on nutrient-loaded zeolite. Acta Hort. 401, 293–299.

Fresenius, W., Quentin, K.E., Schneider, W., 1988. Water Analyis. A Practical Quide to Physicochemical, Chemical and Microbiological Water Examination and Quality Assurance. Springer-Verlag, Berlin.

Hakerlerler, H., Anac, D., Gul, A., Saatci, N., 1992. Topraksız yetiştirme ortamlarının sera koşullarında yetiştirilen marulun azot fraksiyonlarına ve besin maddeleri miktarına etkileri. J. Ege Univ. Fac. Agric. 29 (2–3), 87–94.

Harland, J., Lane, S., Price, D., 1999. Further experiences with recycled zeolite as a substrate for the sweet pepper crop. Acta Hort. 481, 187–194.

Kacar, B., 1972. Bitki ve Toprağın Kimyasal Analizleri. II. Bitki Analizleri. Ankara Üniv. Ziraat Fak. Yay. No. 453.

Kithome, M., Paul, J.W., Lavkulich, L.M., Bomke, A.A., 1999. Effect of pH on ammonium adsorption by natural zeolite clinoptilolite. Commun. Soil Sci. Plant Anal. 30 (9&10), 1417–1430.

Loboda, B.P., 1999. Agroecological assessment of using substrates from zeolite-containing rocks in greenhouse grown sweet peppers. Agrokhimiya. 0 (2), 67–72.

Maloupa, E., Gerasopoulos, D., 1999. Quality production of four cut gerberas in a hydroponic system of four substrates. Acta Hort. 491, 433–438.

Ming, D.W., Dixon, J.B., 1987. Quantitative determination of clinoptilolite in soils by a cation-exchange capacity method. Clays Clay Miner. 35 (6), 463–468.

Mumpton, F.A., 1999. Uses of natural zeolites in agriculture and industry. Proc. Natl. Acad. Sci. U.S.A. 96 (7), 3463–3470.

Oztan, F., 2002. Substrat Kültürü ile Hıyar Yetiştiriciliğinde Organik Gübre Kullanım Olanakları. Ege Üniv. Fen Bilimleri Enstitüsü, İzmir.

Pivert, J., Lane, S., Price, D., Fuller, M., 1997. An examination of the re-use of clinoptilolite zeolite as a long term substrate for sweet pepper. In: Proceedings of the Ninth International Congress on Soilless Culture, St. Helier, Jersey, Channel Islands, pp. 249–256.

Resh, H.M., 1991. Hydroponic Food Production. Woodbridge Press Pub. Com., California.

Van Os, E.A., 2000. New developments in recirculation systems and disinfection methods for greenhouse crops. In: Proceedings of the 15th Workshop on Agricultural Structures and ACESYS, Japan, December 4–5, 2000, pp. 81–91.

Winsor, G., Adams, P., 1987. Diagnosis of Mineral Disorders in Plants, vol. 3. Glasshouse Crops, MAFF/AFRC, HMSO, London, pp. 119–125.

Yucel, H., 1987. Zeolitler ve uygulama alanları. III. Ulusal Kil Sempozyumu, 21–27 Eylül 1987, ODTU, Ankara, pp. 391–402.