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Effect of Particle Size Distribution of Perlite and its Mixture with Organic Substrates on Cucumber in Hydroponics System

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ABSTRACT

The selection of a growing medium is one of the most important decisions in the culture of hydroponic crops. In order to select a suitable medium for hydroponic cucumber (*Cucumis sativus* L. cv. Negin), an experiment was carried out on growing media containing different particle sizes of perlite and organic substrates in a run-to-waste system in a greenhouse experiment. The growing media tested were: very course perlite (VC-P, 70% by volume in the range of 2-3 mm), course perlite (C-P, 70% by volume in the range of 1-2 mm), medium perlite (M-P, 70% by volume in the range of 1 mm), fine perlite (F-P, 70% by volume in the range of 0.5-1 mm), very fine perlite (VF-P, 70% by volume < 0.5 mm), sawdust (Sd) (100%), one mixture of VC-P and Sd (50:50, v/v), one mixture of VC-P and poplar chip (Ch) (50:50, v/v) and one mixture of VC-P and wheat straw (St) (50:50, v/v). The eight treatments were arranged in a randomized complete block design with four replications. The results showed that there were significantly differences in the mean fruit weight, plant height, and leaf area of cucumber with respect to media containing very course (VC)-grade perlite (horticulture-grade perlite) and its incorporation with organic substrates, and media containing different grades of perlite (from very course to very fine-grade perlite). The incorporation of wheat straw (50:50) into VC-grade perlite brought decreases of about 35% in the mean fruit weight of cucumber, respectively. Media containing fine grade-perlite led to a significant increase in mean fruit weight (50%), plant height (25%), and leaf area (70%) of cucumber as compared with media consisting of very course-grade perlite. It was concluded that the medium containing fine-grade perlite had the best performance for cucumber plant growth.

Keywords: Cucumber, Growing media, Hydroponics, Organic substrate, Particle size, Perlite.

INTRODUCTION

Although there is not ideal growth medium suitable for all growing potted plants, a growth medium should combine physical, chemical and biological requirements for good plant growth together with those requirements of practical plant production (to be readily available, easy to handle, lightweight and to produce uniform plant growth) (Landis *et al.*, 1990; Heiskanen, 1993; Reinikainen, 1993). Root distribution in container media can be influenced by particle size distribution. A medium with a high water-holding capacity and low aeration may result in a concentration of roots in the top portion of the container, especially if the medium in the bottom portion of the container remains saturated for extended periods. Roots growing in poorly aerated media are weaker, less succulent and more susceptible to micronutrient deficiencies and root rot pathogens such as *Pythium* and *Phytophthora* than roots growing in well-aerated media (Ingram *et al.*, 2003).

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Particle size distribution is important for describing the physical quality of the material and its suitableness for plant growth. It influences the volume of air and water held by the substrate. The particle size distribution of the materials used as substrate can vary depending on their origin and grinding conditions, among other factors (Ansorena, 1994).

The perlite culture system was originally developed at the West of Scotland College (Hall *et al.*, 1984). It is based on a relatively coarse grade of expanded perlite (horticultural-grade perlite) which has 90% by volume of particles in the range 1 to 5 mm and a very high air-filled porosity (AFP) of around 60%, as measured by the method of Bragg and Chambers (1988). Hitchon *et al.*, (1991) compared the crop performance of glasshouse tomato in horticultural-grade perlite with that in two grades which have much finer particle-size distribution, one with 90% by volume in the range 0.6-1.4 mm, the other 90% by volume < 1 mm. Cumulative yields of fruit were similar in each of the three grades of perlite. They concluded that although the air-filled porosity of the fine-grade perlite was lower than the medium or horticultural-grade material, oxygen availability at the root surface did not limit root function. Recent evidence from trials with plants grown in peat suggests that provided the AFP is greater than 10%, the oxygen availability at the root surface will not limit plant growth and development (Bunt 1988). Even the fine, plaster-grade perlites have AFPs in excess of this value and should, therefore, form the basis of an excellent rooting substrate for hydroponic crop culture.

Highly valuable materials such as soil, peat, sand, perlite and vermiculite are commonly used as substrates for container plant production (Tinus and McDonald, 1979; Landis *et al.*, 1990). Nevertheless, these materials might be fully or partially replaced with various organic waste products such as rice hulls, pine bark, etc., thus achieving environmental benefits since ecosystem damage caused by soil, peat, perlite and vermiculite extraction is avoided and the impact of residue accumulations is minimized. There are also economic benefits, because the use of residues means lower costs (Seilopoulos, 1995; Ingelmo *et al.*, 1998; Webber *et al.*, 1999).

Greenhouse production is now an important sector in Iran. Studies on soil-free culture in Iran have advanced during the last decade. There is, however, lack of information regarding the suitability of organic and inorganic materials and their mixes as growing materials for hydroponic crops in soilless culture system.

The objectives of this study were to determine a suitable growing medium for cucumber in hydroponics system and to study the influence of different grades of perlite on the cropping performance of cucumber.

MATERIALS AND METHODS

Substrate Treatments

The yield of cucumber (*Cucumis sativus* L. cv. Negin), grown using different substrates in a run-to-waste system, was examined in greenhouse experiment at the College of Agriculture, Urmia University in Western Azarbaijan Province (Iran) over a short period (8 weeks). The growing media tested were: very course perlite (VC-P, 70% by volume in the range of 2-3 mm), course perlite (C-P, 70% by volume in the range of 1-2 mm), medium perlite (M-P, 70% by volume in the range of 1 mm), fine perlite (F-P, 70% by volume in the range of 0.5-1 mm), very fine perlite (VF-P, 70% by volume < 0.5 mm), one mixture VC-P and sawdust (Sd) (50:50, v/v), one mixture of VC-P and poplar chip (Ch) (50:50, v/v) and one mixture of VC-P and wheat straw (St) (50:50, v/v).

Very course and course-grades (> 1 up to 5 mm) perlite were defined as normal horticulture perlite (Hitchon *et al.*, 1991).

The eight treatments (8 growing media formulations) were arranged in a

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randomized complete block design with four replications (four bags containing two plants). The air filled porosity (AFP) and water holding capacity (WHC) for each substrate was determined by the submersion method (Bragg and Chmbers 1988) at the beginning of the experiment.

The seeds of cucumber (*Cucumis sativus* L. cv. Negin) were planted in the perlite - filled plastic cups and covered with perlite. The seedlings of cucumber were planted into white polyethylene bags (120×25×15 cm) containing 40 Liters of substrate (10 Liters per plant, 4 plants per bag) and were placed end to end on 10 inches wide PVC (Poly Vinyl Chloride) gutter sections that were supported to a height of 80 cm. The nutrient solution was made up in tap water whose chemical analysis is shown in Table 1. The seedlings were irrigated through a drip tap with a nutrient solution from 0.5 to 3.5 Liters per day, depending on the stage of plant growth. For all substrates the electrical conductivity of the nutrient feed was maintained at 2.0 dS m^{-1} and the pH at 5.8. Cucumber was grown, using strings for support, on wires 2.60 m above the ground. The nutrient solution for cucumber was applied through the irrigation system at the vegetative stage (N:K> 1) containing the following concentration of nutrients: 252 ppm N (NO_3^-), 70 ppm P, 220 ppm K, 200 ppm Ca, 60 ppm Mg, 20 ppm Fe, 2 ppm Mn, 1 ppm Zn, 1 ppm B, 0.1 ppm Cu, 0.2 ppm Mo. Concentrations of N, P, K, and Ca during the reproductive stage (N:K< 1) were 225, 60, 280, and 140 ppm, respectively (Anonymous, 2003). Fertigation was applied 6 times daily for 5 minutes using drippers of 2 L hr^{-1} capacity. The management of the crop, including the nutrient and irrigation regime, was the same for each medium. Cucumber fruit number, fresh weight, leaf area and plant height were recorded for each experimental plant.

Data Analysis

Plant growth parameters of cucumber including plant height, leaf area and fruit weight were analysed using analysis of variance and Duncan's multiple-range tests which were carried out using the CoStat Statistical Package software (CoHort Software, 2002) at P≤ 0.01.

RESULTS AND DISCUSSION

Physical Properties of the Growing Media

Organic and inorganic substrates used in a soil-free culture can differ remarkably in their physical properties. These physical properties affect the air content and retained volume of available water in the substrate. These differences need to be taken into consideration when growing greenhouse crops with varying demands for water and oxygen in the root zone of cucumber. There was a great difference in the physical properties of the studied growing media (Table 2). The water holding capacity (WHC), air filled porosity (AFP), bulk density and total porosity (TP) is vastly different.

Table 1. Chemical analysis of the tap water used in greenhouse cucumber culture.

pH	EC (ds m^{-1})	NO_3	P	K
		mg L^{-1}		
7.8	0.53	4.9	0.0	1.95
Ca	Mg	Na	HCO_3	Cl
		me L^{-1}		
3.9	1.5	0.89	5.6	1.0

Table 2. Physical properties of media used in greenhouse cucumber culture.

Media	Water holding capacity (% vol)	Air filled porosity (%)	Bulk density (g/cm^3)	Total porosity (%)
1-VC [a]-grade perlite (2-3 mm, 100%)	20	62	0.34	82
2- C [b]-grade perlite (1-2 mm, 100%)	33	59	0.27	92
3- M [c]-grade Perlite (1 mm, 100%)	49	42	0.21	91
4- F [d]-grade Perlite (0.5-1 mm, 100%)	42	47	0.18	89
5- VF [e]-grade perlite (<0.5 mm, 100%)	57	32	0.16	89
6- VC-grade perlite: sawdust (50:50, v:v)	66	22	0.18	88
7- VC-grade Perlite: poplar chip (50:50, v:v)	31	62	0.10	93
8- VC-grade Perlite: wheat straw (50:50, v:v)	26	68	0.10	93

[a] VC, very course; [b] C, course; [c] M, medium; [d] F, fine; [e] VF, very fine

Bulk densities of media ranged between 0.08 and 0.34 g cm^{-3}, depending on the composition. Bulk densities values between 0.1 and 0.3 g cm^{-3} are considered acceptable for hydroponic seedlings and crops (Kampf *et al.*, 1999).

Air filled porosities of media were between 2 and 68 percent by volume. One from eleven substrates have AFP smaller than 10%, two were between 20 and 40%, three ranged between 40-60%, and five were smaller than 70% by volume. Container media should contain 50 to 85% pore space. Total porosity of container the media is important, but probably more crucial than this is the portion that is AFP versus WHC. Some plants prefer wet soils while others prefer dry soils. On average, 10 to 30% of the container volume should be composed of air space while 45 to 65% should be water (Altland, 2006).

The amount of WHC was between 20 and 40% by volume for six substrates, between 40 and 60% by volume for one substrates, between 60-80% by volume for one substrate, and smaller than 90% by volume for one substrate (Table 2).

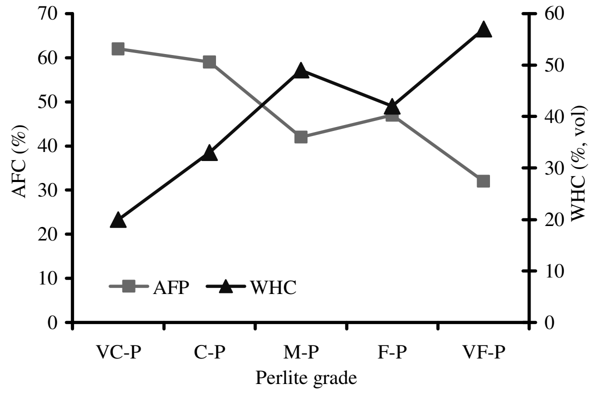

Figure 1. Effect of perlite particle size on air filled capacity (AFP) and water holding capacity (WHC).

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A negative significant relationship was found between air filled porosity and water holding capacity for different grades of perlite (AFP= 82-0.83 WHC, r^2= 0.94, P≤ 0.01). There was a trend of decreasing AFP and increasing WHC with decreasing perlite particle size (Figure 1). The same trend has been reported by other researchers (Wada *et al.*, 2005).

Total porosity and air space were highest in the 75:25 and 50:50 very course perlite: straw substrates (Table 2). Adding wheat straw (50:50 Sd:St) or poplar chip (50:50 Sd:Ch) to sawdust increased AFP. Adding sawdust (50:50 VC-P:Sd) to very course-grade perlite decreased AFP. There was almost a three fold increase in WHC with 50:50 VC-P:Sd substrates compared to the 100% very course-grade perlite. Adding poplar chip (50:50 VC-P:Ch) or wheat straw (50:50 VC-P:St) to very course-grade perlite did not markedly affect AFP and WHC (Table 2).

Media Containing Mixture of Organic and Inorganic Substrates

ANOVA results confirmed that mean fruit weight, plant height, and leaf area of cucumber significantly (P< 0.01) differed with respect to media containing very course-grade perlite (VC-perlite) and its mixture with organic substrates. There was also significantly a difference in plant height over growing period.

A question that comes up if the addition of uncomposted organic substrates to very course-grade perlite (horticulture-grade perlite) can improve its physical and chemical properties to provide a proper medium for plant growth. Duncan's multiple range test indicated that incorporation of organic substrates (sawdust, wheat straw, poplar chip) into very course-grade perlite decreased the fruit weight and plant height and increased the leaf area of cucumber (Figure 2). Cucumber grown in the medium of VC-perlite:sawdust (50:50) were comparable to those grown in VC-perlite

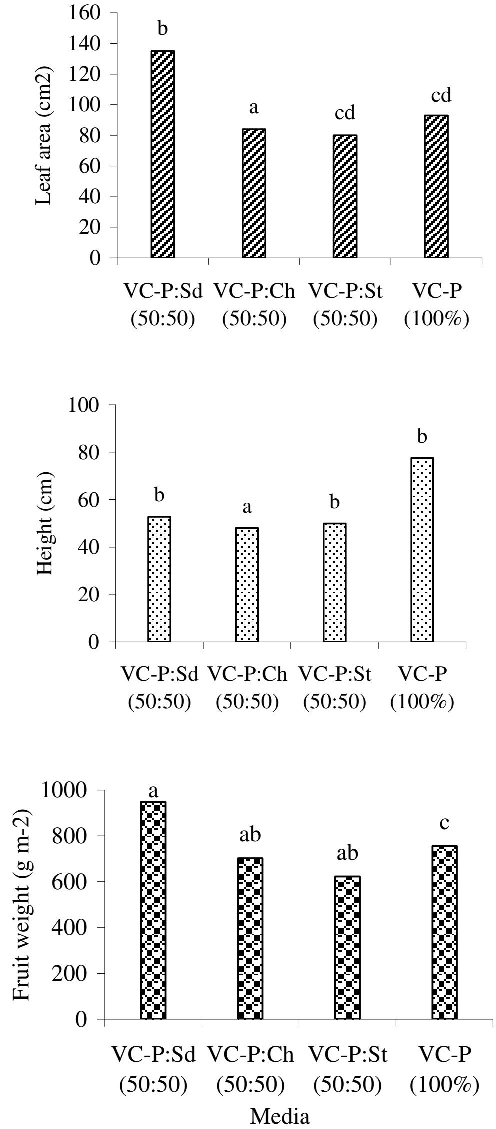

Figure 2. Comparison of media containing VC-perlite (100%), and its mixture with organic substrates (50:50 VC-perlite:sawdust, 50:50 VC-perlite:poplar chip, 50:50 VC-perlite:straw) on cumulative fruit weight, plant height, and leaf area of cucumber.

alone (Figure 4). The highest fruit weight (950 g m^{-2}) and plant height (78 cm) were obtained with VC-perlite (100%) and the lowest fruit weight (337 g m^{-2}) and plant height (48 cm) with the 50:50 VC-perlite:poplar chip, respectively. Cucumber plant grown in VC-perlite media consisting of wood chip (50:50) and cereal straw

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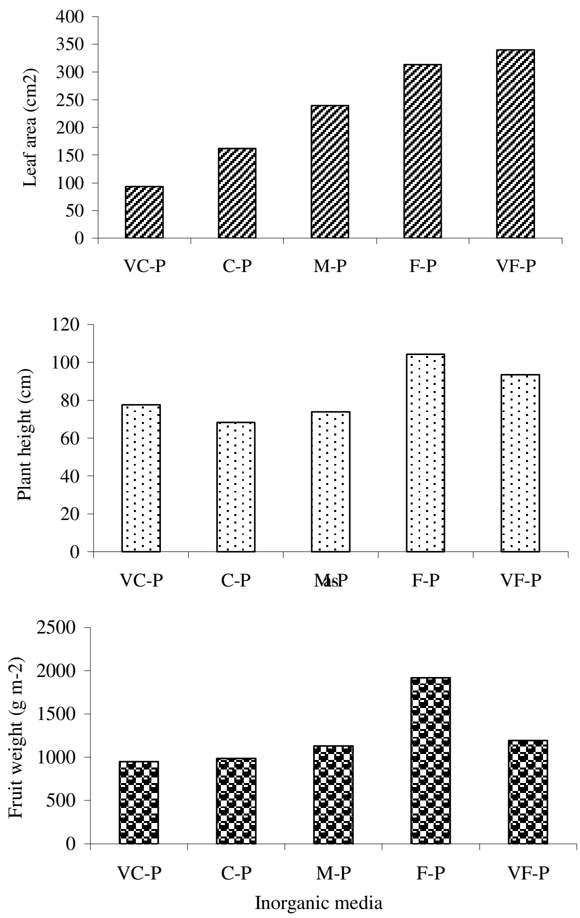

Figure 3. Comparison of media containing inorganic substrates (VC- perlite, C-perlite, M-perlite, F-perlite, VF-perlite, 100%) on cumulative fruit weight, plant height, and leaf area of cucumber.

(50:50) showed a light green induced N deficiency symptom over the plant growing period.

The adverse effects of adding wood products (wood chip) and cereal straw to VC-perlite on the fruit weight and plant height of cucumber could be ascribed to the high C:N ratio of organic substrates and the different speeds of biological decomposition for these substrates at different composting period. Wood products have C:N ratios which are much higher than cereal straw (661:1 *vs.* 100:1) (Allison, 1965). If such uncomposted organic materials are incorporated into a medium containing inorganic substrates like VC-perlite, microorganisms will compete with plant roots for supplied nitrogen in a VC-perlite medium during decomposition. This competition for nitrogen can result in nitrogen deficiency and poor plant growth (Ehrenfeld *et al.*, 1997; Bottner *et al.*, 1999).

Media Containing Different Grades of Perlite and Organic Substrates

The foregoing results indicated that a usual horticulture perlite (VC-perlite, 2-3 mm) was the high performance medium for plant growth in comparison with organic media. A question that comes up if finer grades of perlite will also affect on plant growth parameters of cucumber.

ANOVA results showed that fruit weight, plant height and leaf area of cucumber were

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significantly affected by particle size distribution in perlite.

Results of mean separation indicated that media containing fine grades of perlite brought about an increase in mean fruit weight, plant height, and leaf area of cucumber as compared with media consisting course grades of perlite (Figure 3). The highest fruit weight (1917 g m^{-2}) and plant height (104 cm) were obtained with a fine-grade perlite and the highest leaf area (340 cm^2) with a very fine-grade perlite. The lowest fruit weight (951 g m^{-2}) and leaf area (93 cm^2) were obtained with very course-grade perlite and the lowest plant height (68 cm) with course-grade perlite. This means that plants grown in fine grades of perlite produced more fruit weight, plant height, and leaf area than those grown in course grades of perlite.

The very good performance of cucumber plants grown on media consisting of fine-grades of perlite could presumably be attributed to particle size distribution. Particle size affects the physical properties, especially the air/water relationships. As mentioned previously, water holding capacity increased and air contents decreased with decreasing particle diameter (Table 2). The aeration porosity, defined by the large pores, should be at least 20-25% and as high as 45% under warmer greenhouse conditions where there is increased demand for oxygen by roots, as well as an increased production of carbon dioxide (Spomer, 1979). Media with high aeration have shown reduced plant growth due to low water retention and increased susceptibility to drought (Bugbee and Frink, 1986). Accordingly, the inferior performance of plants grown on media containing course-grades of perlite as compared to fine-grades of perlite could be ascribed to their low water holding capacity rendering the plants susceptible to water stress (Table 2).

CONCLUSIONS

It was found that there were significant differences in plant growth parameters including mean fruit weight, plant height, and leaf area of cucumber with respect to growing media containing horticulture-grade perlite (very course-grade perlite) and its incorporation with organic substrates, different grades of perlite (from very course to very fine grade-perlite). The incorporation of organic substrates (sawdust, cereal straw, wood chip) into horticulture-grade perlite brought about a significant decrease in plant growth parameters. The highest mean fruit weight, plant height, and leaf area of cucumber were recorded for growing media containing fine-grade perlite. It was found that the medium containing fine-grade perlite had the excellent performance for cucumber plant growth. With regard to future growth of a soil-free culture with perlite substrate, it is important to make operational additional research projects for vegetables and flowers grown in fine grades of perlite, with the objective of building further confidence in the advantages of this type of cultivation.

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اثر توزیع اندازه ذرات پرلیت و بسترهای آلی بر خیار در سیستم هیدروپونیک

ع. صمدی

چکیده

یکی از اقدامات مهم در کشت محصولات هیدروپونیک انتخاب بستر کشت مناسب می باشد. به منظور انتخاب بستر کشت مناسب،آزمایش گلخانه ای در شرایط کشت بدون خاک از نوع سیستم باز با استفاده از بسترهای کشت حاوی مواد مختلف آلی و معدنی بر روی خیار (*Cucumis sativus* L.) رقم نگین (Negin) انجام گردید. بستر های مورد آزمایش عبارت بودند از: پرلیت خیلی درشت (VC-P، ۷۰٪ حجمی در محدوده ۲-۳ میلیمتری)، پرلیت درشت (۷۰٪ حجمی در محدوده ۱-۲ میلیمتری)، پرلیت متوسط (۷۰٪ حجمی در محدوده ۱ میلیمتری)، پرلیت ریز (۷۰٪ حجمی در محدوه ۰/۵-۱ میلیمتری)، پرلیت خیلی ریز (۷۰٪ حجمی کمتر از ۰/۵ میلیمتری)، یک مخلوط ترکیبی از VC-P و Sd (۵۰:۵۰، v/v)، یک مخلوط ترکیبی از VC-P و تراشه چوب صنوبر (Ch) (۵۰:۵۰، v/v)، یک مخلوط ترکیبی از VC-Pو کاه و کلش گندم (St) (۵۰:۵۰، v/v). هشت تیمار در چهار تکرار در قالب طرح آزمایشی بلوکهای کامل تصادفی به اجرا در آمد. نتایج حاصل نشان داد تفاوت معنی داری در میانگین وزن میوه، ارتفاع گیاه، و سطح برگ خیار در ارتباط با بسترهای کشت حاوی پرلیت خیلی درشت (پرلیت باغبانی) و مخلوط آن با مواد آلی (خاک اره، کاه وکلش گندم، تراشه چوب صنوبر)، و بسترهای کشت حاوی اندازه ذرات مختلف پرلیت (از خیلی درشت تا خیلی ریز) وجود داشت. اضافه نمودن کاه و کلش گندم (۵۰٪) به پرلیت خیلی درشت سبب کاهش معنی دار در وزن میوه خیار (۳۵٪) گردید. بسترهای کشت حاوی پرلیت ریز در مقایسه با بسترهای کشت حاوی پرلیت خیلی درشت موجب افزایش معنی دار در میانگین وزن میوه (۵۰٪)، ارتفاع گیاه (۲۵٪)، و سطح برگ (۷۰٪) خیار گردید. بیشترین کارایی زراعی گیاه خیار در بستر کشت حاوی پرلیت ریز بدست آمد.

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