Do Algae Cause Growth-Promoting Effects on Vegetables Grown Hydroponically?

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Abstract

Fertigation systems, especially hydroponic systems with recirculating nutrient solution, are an ideal environment for algal growth, but it is not clear if this contaminant affects the crop. Therefore, greenhouse experiments were carried out to monitor the development and composition of algae, as well as their effects on lettuce and cucumber performance. In addition, several different substrates and water sources, with differing algal communities, were tested for their effects of on both algae growth and crop performance. In open troughs, algal density was lg 4.2 to 4.6 cells/ml in the lettuce and lg 3.7 to 4.6 cells/ml in the cucumber experiment. Algal density and composition were mainly influenced by initial density in the different water sources. Moreover, plant species, temperature, and concentration of the nutrient solution also affected the density. The diversity of the algal community was poor; only unicellular species were observed with *Chlamydomonas* spp. and *Pseudodictyosphaerium* spp. as main representatives in the drain water. Cucumber and lettuce shoot fresh weight, and therefore lettuce yield, were reduced significantly in the presence of algae, but cucumber yield was not affected. Overall, the present results indicate that the effects of algae depend on several factors, and therefore do not enable generalization on whether algae have a negative or positive impact on crop growth in hydroponic systems.

Keywords: fertigation, clogging, recirculation.

Introduction

Algae often thrive in fertigation systems, particularly when there is sufficient light, and they can cause problems with the water supply system by clogging drippers or drip lines (Ravina *et al.*, 1997). In addition, algae compete for nutrients, and certain species are known to produce toxins that might inhibit or even stop crop growth (Huizebos *et al.*, 1993; Borowitzka, 1995). Therefore, one common means to prevent, or at least reduce, algal growth is to cover the root system with black plastic sheets. Alternatively, algaecides are used occasionally (Vänninnen and Koskula, 1998; Nonomura *et al.*, 2001). These precautions cause additional costs for the farmer, and also produce pollutants.

However, algae may also be beneficial for plant growth. The oxygen produced by algal photosynthesis prevents anaerobiosis in the root system of the crop. Furthermore, algae recently have been reported to release plant-growth promoters in plant cultivation systems (Mazur *et al.*, 2001). Among these plant-growth regulators are auxins, cytokinins, gibberellins, abscisic acid, and ethylene (Van Staden, 1999). Other growth-promoting effects may be more indirect, e.g., enhancing the water-holding capacity of soils or substrates, improving the availability of plant nutrients (Möller and Smith, 1998), or producing antifungal and antibacterial compounds (Cannell, 1993; Borowitzka, 1995). Very little is known about the positive or negative effects of algae that occur naturally in fertigation systems, although several green algae, such as *Scenedesmus* spp. and *Chlorella* spp. were reported to excrete plant growth-promoting substances (Ördög, 1999; Mazur *et al.*, 2001).

Therefore, two experiments were carried out to answer the following questions:

- Is the cultivation of algae in fertigation systems, such as hydroponics, possible?
- Does the water source affect the algal density and composition in the cultivation systems?
- Do the characteristics of the plants and substrates affect algal development during cultivation?
- Does the algal community influence plant growth?

Material and methods

Water sources and characterization of algae

Water from several different sources at or close to Grossbeeren (Germany, lat. 52°N; long. 13°E) was used for mixing the nutrient solutions in our experiments. The sources were: a) a rainwater pond, b) a peat ditch, and c) osmotic water.

The nutrient solution contained: as macro-nutrients (mM), NH_4NO_3 (1), $Ca(NO_3)_2 \cdot 4H_2O$ (4.5), KNO_3 (7.5), KH_2PO_4 (2), K_2SO_4 (1), $Mg(NO_3)_2$ (1); and as micro-nutrients (µM), FeEDTA (40), $MnSO_4$ (5), H_3BO_4 (30), MoO_3 (0.5) $CuSO_4$ (0.75), $ZnSO_4$ (4) (De Kreij *et al.*, 1999). The algal density and composition were characterized in all water sources before the experiments and in the nutrient solutions frequently during the experiments. The samples were examined under a light microscope. Species were quantified by means of a NEUBAUER counting chamber and their populations expressed as cells per millilitre.

Greenhouse experimental setup

Head lettuce (*Lactuca sativa* var. *capitata* cv. Charlen) plants aged 20 days were transferred to a 200-m^2 greenhouse, where they grew in 20 troughs measuring $8.0 \times 0.2 \times 0.07$ m from March 5 to April 11, 2002. Each trough contained 37 lettuce plants. Six treatments were applied, in a twofold cross classified design, with trough cover and hydroponic system as treatment factors, in three replications. Half of the troughs were covered with a black/white plastic sheet to prevent algal growth (A-) and the other half were not (A+). The second treatment factor was the substrate used: vermiculite, a polyester fleece, and no substrate (Nutrient Film Technique). Black polyester fleece (80 $g \cdot m^{-2}$) covered the bottoms of the troughs, which were filled to the brim with vermiculite. The first treatment was chosen to investigate the algal density and its influence on lettuce growth. The second treatment was chosen to check whether the growth medium and hence, the conditions in the root environment affect algal density and population composition. Nutrient solution was supplied intermittently, depending on the radiation level, for 45 s every 2 to 15 min, at 2 l per trough. The solution was supplied via TSX-510-15-1000 drip lines (Tee Jet) put on the substrate surface. The solution EC was set to 2.5 dS/m and pH to 6.0.

Cucumber (*Cucumis sativus* cv. Corona) plants aged 20 days were transferred to a 200 m^2 greenhouse, where they grew in 18 troughs measuring $8 \times 0.2 \times 0.07$ m from 10 March to 11 April 2005. Each trough contained 11 cucumber plants. Six treatments were applied, in a twofold cross classified design, with trough cover and water source as treatment factors, in three replications. Half of the troughs were covered with a black/white plastic sheet to prevent algal growth (A-) and the other half with a transparent plastic sheet (A+). The second treatment factor was the water source, as mentioned above. The first treatment factor was chosen to investigate the algal population and its influence on cucumber growth. The second treatment was chosen to check whether the water source affected algal density and population composition, and hence, plant growth and yield. Nutrient solution was supplied continuously at about 2 L/min via drip lines with a dripper for each plant, by means of a Nutrient Film Technique. The solution EC was set to 3.0 dS/m and pH to 6.0.

Greenhouse temperature controls were set to heat if temperatures dropped below 15/12°C (day/night) for lettuce and below 22/19°C for cucumber. Ventilation was started if the temperatures exceeded 18 and 28°C, respectively. Humidity and CO_2 concentration were ambient and not controlled. The micro-climates in the greenhouse, the EC and pH in the drains from the troughs, and the temperatures in the root environments were monitored.

Yield, shoots, and roots were harvested and fresh and dry weighed. Fresh samples were taken from the root system (50 mm from the rock-wool cube) to measure specific root length (Tennant, 1975) and mean root diameter. Total root length per plant was calculated as the product of specific root length and total root dry weight.

Results and discussion

Population dynamics of algae

The algal density was about 9,000 cells/ml in rain water and at the start of the experiments. It was lower in the other water sources and zero in the osmotic water. After water was supplied to the troughs covered with the black/white foil the algal density decreased continuously in both experiments until 2-3 weeks after the start, when no cells were found by microscopic examination. In contrast, in the open troughs and in those covered with a transparent foil the algal density increased to a maximum of about 35,000 cells/ml and remained fairly constant at this level in the lettuce experiment (Fig. 1). In the cucumber experiment algal density remained at this level only when rainwater was used. The density in the cucumber troughs supplied from the other water sources was about half of the above figure, and it diminished to 7,000 cells/ml at the end of the experiment. Density was affected by the substrates and by the water sources (Fig. 2A, B). Overall, the algal density was highest on vermiculite and least on the fleece, with intermediate density where there was no substrate. In the cucumber experiment the highest density was observed in the rainwater, followed by water from the peat ditch, and was least in the osmotic water. Cultivation of algae was simple although it was not found possible to maintain a constant density or a specific composition. This difficulty was attributed to likely variations in micro-climate and nutrition, such as substrate temperature and nutrient solution EC. Climatic and nutritional effects on algal density in water from natural sources were reported by Sunda and Huntsman (1998) and Wetzel (2001), and this might also account for the decrease in algae density in the drain solution at the end of the present cucumber experiment. Although the filamentous *Ulothrix* spp. could have caused filter clogging (Juanica *et al.*, 1995; Ravina *et al.*, 1997), we did not observe any problems, most likely because of the low temperature in the lettuce experiment and the relatively short cultivation period in the cucumber experiment.

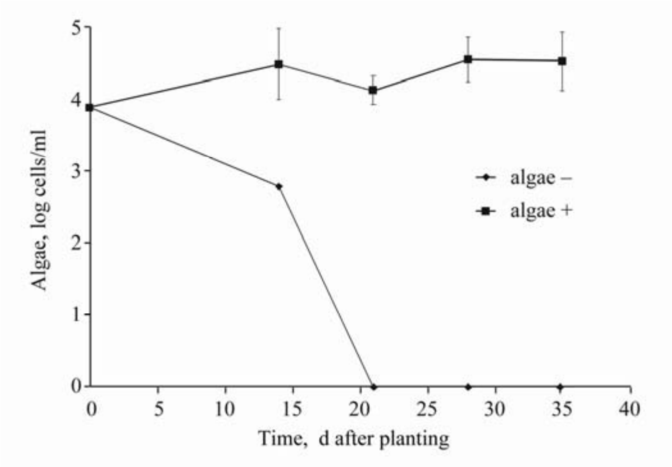

Fig. 1. Algal density in the lettuce experiment. In the "+" treatment troughs were covered with a black/white plastic foil; in the "-" treatment troughs were not covered.

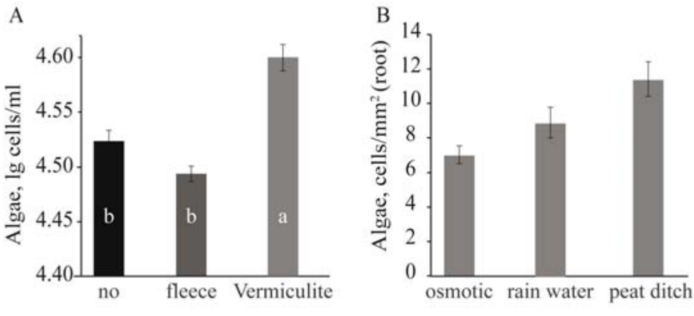

Fig. 2. Algal density three weeks after start of experiment. A: in the drain solution (lettuce experiment) when three different types of substrate were used; B: on the cucumber roots when three different water sources were used.

Prior to the start of the greenhouse experiment, the water samples exhibited a low algal diversity compared with previous results (Schwarz *et al*., 2005; Table 1), which were mostly obtained with *Pseudodictyosphaerium* spp., *Scenedesmus longispina*, *Chlamydomonas variabilis*, *Chlorella vulgaris*, and *Klebsormidium* sp. In the greenhouse studies examples of *Monoraphiodium* spp. and *Micractinium* spp. were found only in samples with water from the natural lake. Only species of *Chlamydomonas* spp. in lettuce and *Pseudodictyosphaerium* spp. in cucumber persisted throughout the experiment, and were also found later in the experiment in samples of nutrient solutions based on osmotic water. The density of the most frequently found *Chlamydomonas* spp. varied between 10 and 36,000 cells/ml (Fig. 3). The other algae species were found at lower densities, with a maximum of about 600 cells/ml (data not all shown). Species of *Chlamydomonas* are known to become dominant in closed hydroponic systems and may limit the growth of other species. Indeed, Nonomura *et al*. (2001) reported *Chlamydomonas* spp. as the prevalent algae in hydroponic systems at five different locations in Japan: depending on the location, *C. reinhardtii*, *C. angulos*, or *C. umbonata* were found, whereas other genera, including *Ulothrix* and *Scenedesmus*, were rare. In the present study, the troughs contained these unicellular species mentioned and in addition species of the filamentous genus *Ulothrix* forming large colonies within the root system (not quantified).

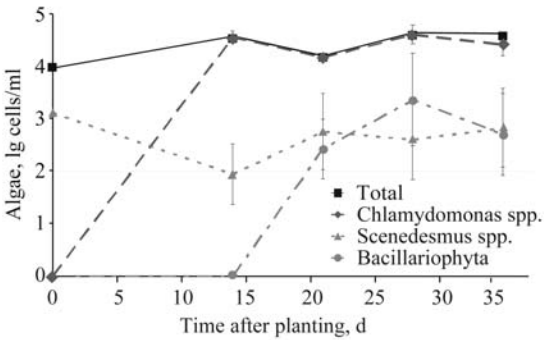

Fig. 3. Density of the three main algae species in the drain solution of the cucumber experiment.

Table 1. Occurrence of algae in different water sources investigated before start of experiments (xxx = very frequent, xx = frequent, x = rare).

Algae species	Rain water	Osmotic water	Peat ditch	Natural lake
Pseudodictyosphearium spp.	xxx	xxx	xxx	xxx
Chlamydomonas variabilis	xx	xx	xx	xx
Scenedesmus longispina	xx	xx	xx	xx
Ulothrix spp.	xx	xx	xx	
Klebsormidium spp.	xx	xx	xx	
Chlorella vulgaris			x	x
Monoraphiodium spp.				x
Micractinium spp.				x

Plant growth analysis

Algae treatment had no effect on cucumber yield but it reduced the fresh weight of the lettuce heads and cucumber shoots significantly (Fig. 4). Shoot dry matter of both plant species was also reduced. On the other hand, shoot and root dry matter percentages were greater in the treatments with algae than in those with no algae. No interactions were found between algae treatments and the other factors tested, i.e., substrate and water source. However, these two factors affected several plant growth characteristics, particularly of the root system and, therefore, the shoot/root ratio (data not shown).

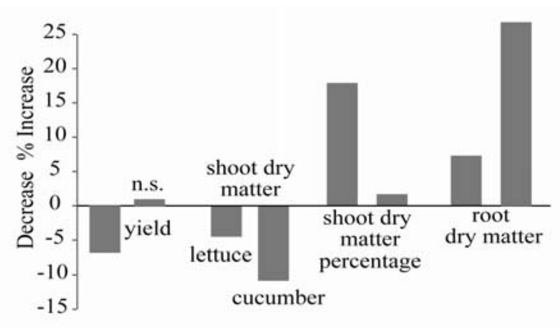

Fig. 4. Effects of algal treatment on lettuce and cucumber yields, on shoot and root dry matter contents and percentages; depicted as relative values compared with the treatments containing no algae.

Both *Chlamydomonas* spp. and *Scenedesmus* spp. are known to promote plant growth (Ördög, 1999). *Chlamydomonas* spp. are known to produce extracellular mucilage (Allard and Tazi, 1993), and *Scenedesmus* spp. reportedly exhibit weak auxin-like and cytokinin-like activity (Mazur *et al*., 2001). In light of the release of these hormones, plant-growth stimulation could have been expected. Indeed, in the cucumber study plant growth-promoting effects were observed, especially on the root systems of the plants. On the other hand, uptake processes were impaired in the lettuce experiment. The release of extracellular polysaccharides by *Chlamydomonas* spp. could have affected roots directly through their water and nitrogen uptake (Allard and Tazi, 1993). An indicator of this effect was that the specific root length was significantly reduced and the root diameter significantly increased in the A+ treatment (Schwarz and Gross, 2004). Changes in root morphology were accompanied by an increase of the total weight but not in the length of the roots, therefore, it could also be concluded that the algae released compounds other than polysaccharides that affected the roots. When investigating extract of brown algae (*Ascophyllum nodosum* and *Laminaria hyperborea*) Möller and Smith (1998) found various phenolic compounds responsible for growth inhibition of lettuce seedlings. Interestingly, at lower concentrations these compounds stimulated root growth; however, Möller and Smith (1998) did not report whether and/or how the root characteristics were affected.

In the present study, and as reported by Schwarz and Gross (2004) lettuce heads in treatment A+ showed a slight reduction of nitrogen concentration (data not shown here). It is unlikely that this reduction was caused by the competition for nutrients by the algae. Based on the nitrogen accumulation of <2.9 $g/m^2/yr$ reported by Sirenko (1999), we calculated that algae use nitrogen at <1 g/m^2 during the lettuce production period (dry weight accumulation rate, 0.1 $g/m^2/d$; N concentration, 3%), which is less than 10% of the total N uptake of 15 g/m^2 by lettuce and is, therefore, insignificant for the production in a hydroponic system.

In the present study variations in root environmental conditions in the hydroponic systems affected plant roots and, to a lesser extent, algal density and composition. Similar effects on root characteristics and also on the root/shoot ratio were well described in other works (Schwarz *et al*., 1995; Sonneveld and de Kreij, 1999) and will not be discussed here. Although not significantly confirmed by the present data, it was observed that substrates with a large surface area, such as vermiculite, exhibited a positive relation to algal density and also to enhanced plant growth. This should be tested in further studies.

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