Yield and Quality of Lettuce Grown in Floating System Using Different Sowing Density and Plant Spatial Arrangements

M. Gonnella and F. Serio
Istituto sull'Orticoltura Industriale, CNR
Bari, Italy
e mail: iorimg14@area.ba.cnr.it

G. Conversa and P. Santamaria
Dipartimento di Scienze delle Produzioni Vegetali, University of Bari
Bari, Italy

Keywords: leafy vegetables, ready-to-use products, nitrate, hydroponic

Abstract

Baby leaf vegetables (rocket, lamb's lettuce, headless lettuce, endive, escarole, water cress) are mostly requested for mixed salads. Small-size leafy vegetables can be profitably cultivated in a floating system to obtain fresh market products or ready-to-use salads that are arousing more and more interest in consumers. Among hydroponic methods, the floating system is the easiest and cheapest way to produce baby leaf vegetables when soil cultivation is not feasible any more. When re-circulation of nutrient solution (NS) is used, this system shows high water and fertiliser efficiency and low environmental impact. In the present study two cultivars of lettuce (*Lactuca sativa* L. var. *longifolia*) were used: 'Ronda' and 'Amadeus'. The growing cycle was carried out in the greenhouse in March-April 2000. The growing set-up consisted of benches containing the NS and the floating boards. Two plant densities were adopted: 316 and 620 plant/m^2. The latter was obtained using two different plant spatial arrangements. After 40 days of growth, fresh leaf yield was on average near to 6 kg/m^2. Leaf dry matter content was on average 5 g/100 g of fresh weight (f.w.) without any differences between treatments. Contents of inorganic anions and cations were determined both in leaves and roots. Nitrate (NO_3) content was generally lower than 2,000 mg/kg of f.w. and was not influenced by the treatments. Water consumption was near to 80 L/m^2 regardless of plant density, while WUE resulted on average 3.5 g of leaf dry matter produced per litre of water consumed.

INTRODUCTION

Baby leaf vegetables (i.e. rocket, lamb's lettuce, headless lettuce, endive, escarole, water cress) are arousing more and more interest in consumers, mostly requested for mixed salads, both as fresh market products and ready-to-use vegetables.

The production of ready-to-use salads requires first quality raw materials from an organoleptic and hygienic viewpoint (no presence of pesticides, crop or substrate residues). Another important quality feature for leafy vegetables, and especially for minimally processed products, is a low nitrate content. Nitrate content is controlled by Electrical Conductivity Regulation (no. 466/2001) for lettuce and spinach. For minimally processed vegetables nitrate content should be more carefully controlled because of the particular environmental conditions that occur in the packaging (low oxygen level, high humidity and presence of cut portions of tissues) enhancing nitrate reduction to nitrite, which is effectively dangerous.

Among hydroponic methods, the floating system is the easiest and cheapest way to produce baby leaf vegetables when soil cultivation is not feasible any more. When re-circulation is used this system shows high water and fertiliser efficiency and low environmental impact.

Hydroponic systems allow a direct control of the nutrient supply, making possible the instant modification of the composition and concentration of the NS in order to reach a fixed qualitative standard as regards the dry matter content (or crunchiness) or the nitrate content or other organoleptic and aesthetic features of products (Elia et al., 1999).

Small-size leafy vegetables can be profitably grown in a floating system (Gonnella et al., 2001).

In order to produce leafy vegetables suitable to obtain ready-to-use products growing systems are required that can shorten growing cycles, improve uniformity of growth and automation of cultural techniques, in addition to providing high hygienic and quality levels.

Our previous trials of floating cultivation of baby leaf species provided an acceptable yield and a good control of quality parameters, including the nitrate content that could be successfully decreased by some expedients such as the withdrawal of nitrogen from the NS or the replacement of the NS by water in the last period of the growing cycle (Gonnella et al., 2001; Elia et al., 1999).

In this trial the aim was to grow two cultivars of mini-romaine lettuce in a floating system and to characterize their production and their suitability to the growing system also in relation to plant spatial arrangements and densities.

MATERIALS AND METHODS

The trial was carried out in the greenhouse of the experimental farm “La Noria” of the Istituto sull’Orticoltura Industriale – CNR – in Mola di Bari (Southern Italy).

Plants were grown in a floating system consisting of expanded polystyrene boards floating on the NS contained by rectangular ebb-flow benches, approximately 2 m^2 large.

Two romaine lettuce cultivars (*Lactuca sativa* L. var. *longifolia*), ‘Ronda’ and ‘Amadeus’ (Rijk Zwaan) (both defined as mini-romaine lettuce that combine a good, strong leaf structure with an upright habit for ease of harvesting), were sown on 17/03/2000 upon 6 boards each cultivar on 3 benches as a whole, arranged in a completely randomized design with two replications.

Sowing was carried out manually on perlite. After sowing, seeds were covered with vermiculite. Each bench contained 4 rectangular boards with 99 splits 0.3 cm wide, 17 cm long and 2.5 cm apart, organised in three groups. All the arrangements regarding the system and its management are the same as a in previous paper (Gonnella et al., 2001).

Two plant densities were adopted: 316 and 620 plant/m^2. The first was obtained by placing 4 seeds per row (17 cm long), sowing one every two rows (successively indicated as ‘4/1’). The latter density was obtained using two different plant spatial arrangements compared to the previous one: a) less space between seeds on the same row (8 seeds) and the same distance between rows (‘8/1’) and b) the same distance between seeds (4 seeds) but less space between rows (every row sown) (‘4/0’).

After emergence, rain-water in the benches was replaced with a 1/2 strength Johnson’s NS (Johnson et al., 1957), and then with the full strength solution when seedlings developed their first true leaf. The NS, containing 200, 60, 240, 170, 40 and 50 mg/L of N, P, K, Ca, Mg and S, respectively, was prepared from rain-water and the following compounds: $Ca(NO_3)_2$, KNO_3, $MgSO_4{\cdot}7H_2O$, KH_2PO_4, while micronutrients were supplied according to Johnson et al. (1957).

The NS consumption was restored by adding water or fresh NS except for the last week of the growing cycle when the NS was renewed because of the large increase in its electrical conductivity (EC) due to high transpiration. The pH was maintained between 5.5 and 6.5 by daily addition of 5 M H_2SO_4.

At harvest (40 days after sowing) plants were measured for leaf number and height and leaf and root fresh mass.

All plant material was dried in a thermo-ventilated oven at 65 °C until reaching a constant mass, then plant dry samples were submitted to quantitative chemical analysis of total N determined by Kjeldahl method (by Kjeltec 2300 auto analyser, Foss-Tecator, Hillerød, Denmark) by adding salicylic acid to recover NO_3-N. Main inorganic anions and cations were determined by ion chromatography (Dionex DX500, Dionex Corp., Sunnyvale, CA) according to the procedure reported by Santamaria and Elia (1997). Reduced nitrogen was calculated as the difference between total N and NO_3-N. Data were subjected to the SAS’ (Cary, NC) general linear model procedure.

The water and N efficiency were also computed.

RESULTS

After 40 days of growth, fresh leaf yield was on average 6 kg/m^2 for the higher plant density, 20 % more than the lower density (tab. 1). At the same time leaves were slightly longer and less numerous at the higher density, while leaf dry matter content was not significantly different between treatments (tab. 1).

Lower plant density showed lower root weights (- 19 %) with higher dry matter content (+ 18 %) compared to the spatial arrangements giving the higher density (tab. 1).

Leaf yield of 'Ronda' were higher than 'Amadeus' (+ 9 %) produced by longer plants with bigger root fresh weight (tab. 1).

Inorganic anion and cation contents in leaves showed no significant difference due to treatments. Mean leaf nitrate content was about 2,000 mg/kg f.w. (tab. 2). Chloride, K^+ and Ca^{2+} contents were on average 0.7, 5.9 and 1.1 g/100 g dry weight (d.w.) in leaves. Leaf ash content was 17.2 g/100 g d.w. (tab. 2)

Kjeldhal N content in leaves was not different between treatments showing a mean value of 4.1 g/100 g d.w., 80 % accounted for by reduced N. Nitrogen use efficiency was on average 24 g d.w./g N (tab. 3).

Water use efficiency was 3.5 g d.w./L of consumed water.

DISCUSSION

The two mini-romaine lettuce cultivars showed a very satisfying yield, the highest compared to all the species previously tested in our trials in a floating system. Lamb’s lettuce yielded something more than 2.0 kg/m^2 with a similar cycle as regards both the shortness (40 days for lettuce and 50 days for lamb’s lettuce) and the cultural techniques and cultivation period (Gonnella et al., 2001).

In mini-romaine lettuce the highest yield was obtained at the higher plant density. The definition of the optimal plant density for a vegetable grown in a floating system is imperative to obtain high yield and quality levels of products, especially referring to leaf height, crunchiness and nitrate content.

The leaf dry matter content in mini-romaine lettuce was lower than lamb’s lettuce (4.8 g/100 g f.w. vs. more than 7 g/100 g f.w., reported by Gonnella et al., 2001) but probably it was mainly determined by the greater incidence of the midrib in romaine lettuce leaves. This parameter is important for handling resistance (especially during washing) of vegetables intended for ready-to-use products.

So as in our previous trials, in this study we also obtained clean products, with no discarded parts or residuals from substrates and pesticides (no chemical treatment was applied during the trial).

Leaf nitrate content in mini-romaine lettuce was definitely low compared to the electrical conductivity limits set for greenhouse and open field products (2,500 mg/kg f.w.).

High plant densities, like those realised in baby leaf crops, limit leaf expansion and promote leaf lengthening, contributing to increased nitrate accumulation in edible portions. The longer the leaves, the greater is the weight of petioles and midribs on the whole leaf, notoriosly characterised by higher NO_3^- content than in the leaf blade (Pate, 1973). The lower nitrate content obtained in lettuce both confirms and denies this hypothesis: it may be accounted for by the lower plant density compared to those applied in previous trials, but the greater weight of midribs on the whole leaf in romaine lettuce would suggest a higher nitrate content.

The floating system is static compared to NFT and aeroponics. Moreover, the expanded polystyrene floating devices prevent free gas exchange between the NS and the greenhouse air. In a study aimed at optimising the root environment in floating grown lettuce, Both et al. (1999) used a relatively large solution volume per plant (8 L/plant) even if an accurate and continuous control of dissolved oxygen concentration was made during the experiment. In our study this ratio was much lower and at the end of the growing cycle the available NS volume did not succeed in avoiding oxygen deficiency especially in relation to high temperature and fast transpiration. For lettuce, Goto et al. (1996) found a critical dissolved oxygen concentration for root respiration of around 2 mg/L, confirming the value found by Chun and Takakura (1994) of 2.5 mg/L for 34 day-old lettuce plants. In our trial, the oxygen value decreased dramatically in the last part of the cycle (fig. 1) but in spite of this no symptom of oxygen deficiency was shown by plants.

Electrical conductivity remained quite steady in the NS, except for the last week of the growing cycle when electrical conductivity increased excessively due to high transpiration rate. On the other hand this could have been prevented if the previous re-integrations of the consumed NS had been carried out using more diluted fresh NS. The usual pH increase due to NO_3-N absorption was recorded and a daily correction with acids was needed.

The main problems to be solved with this growing system regard the NS pH and electrical conductivity control, as in every closed soilless system. But more attention must be paid to solution oxygen enrichment, since when the dissolved oxygen level drops under the critical concentration for a certain species at a certain phase plants may be stressed.

It may be concluded that, except for these technical aspects that become routine operations with experience, baby leaf vegetable cultivation in a floating system proves to be easy, cheap and suitable to provide a good quality product without relevant release of fertilisers into the environment if a careful management of NS is maintained.

ACKNOWLEDGEMENTS

This work was carried out by funding from ‘Controllo del contenuto dei nitrati nelle produzioni orticole’, project ‘Centro per la commercializzazione dei prodotti agro-alimentari ed ittici’ of the Consorzio Interuniveristario Regionale Pugliese.

Literature Cited

Both, A.J., Albright, L.D., Scholl, S.S. and Langhans, R.W. 1999. Maintaining constant root environment in floating hydroponics to study root-shoot relationships. Acta Hort., 507: 215-221.

Chun, C. and Takakura, T. 1994. Rate of root respiration of lettuce under various dissolved oxygen concentration in hydroponics. Envir. Control Biol., 32 (2): 125-135.

Elia, A., Serio, F., Gonnella, M. and Santamaria, P., 1999. Growing nitrate free endive in soilless systems. Acta Hort., 481: 267-271.

Gonnella, M., Conversa, G., Santamaria, P. and Serio, F. 2001. Production and nitrate content in lamb’s lettuce grown in floating system. International symposium of growing media and hydroponics, 8 – 14 settembre 2001, Alnarp (Sweden), in press.

Goto, E., Both, A.J., Albright, L.D., Langhans, R.W. and Leed, A.R. 1996. Effect of dissolved oxygen concentration on lettuce growth in floating hydroponics. Acta Hort., 440: 205-210.

Johnson C.M., Stout P.R., Broyer T.C. and Carlton A.B. 1957. Comparative chlorine requirements of different plant species. Plant Soil, 8: 337-353.

Pate, J.S. 1973. Uptake, assimilation and transport of nitrogen compounds by plants. Soil Biol. Biochem., 5: 109-119.

Santamaria, P. and Elia, A. 1997. Producing nitrate free endice heads: effect of nitrogen form on growth, yield and ion compositionof endive. J. Amer. Soc. Hort. Sci., 122: 140-145.

Tables

Table 1. Yield of romaine lettuce plants as affected by cultivars and sowing density and spatial arrangement at the end of the growing cycle.

	Leaves			Root fresh weight	Leaves	Roots	Leaf NO_3
	Yield (kg/m^2)	Number (n.)	Height (cm)	(g/m^2)	Dry matter (g/100 g f.w.)		(mg/kg f.w.)
Cultivar							
Amadeus	5.5	10	19	280.7	4.9	6.7	2,126
Ronda	6.0	10	21	366.3	4.9	6.3	1,818
Sp. arrangem.-density							
4/0-620 plants/m^2	6.0 a	9 b	20 a	324.2 ab	4.9 a	6.2 b	1,994 a
4/1-316 plants/m^2	5.1 b	13 a	19 b	280.8 b	4.9 a	7.2 a	2,015 a
8/1-620 plants/m^2	6.2 a	8 b	20 a	365.6 a	5.0 a	6.0 b	1,907 a
Significance (1)							
Cultivar	**	**	*	ns	ns	**	ns
Spatial arrangement	*	ns	**	**	ns	ns	ns
Cv.*Sp. arrangem.	ns	ns	ns	ns	ns	ns	ns

(1) Significance of F: ns, *, **, respectively, not significant, P<0.05, P<0.01.

Table 2. Main inorganic anion, cation and ash contents in romaine lettuce leaves as affected by cultivars and sowing density and spatial arrangement at the end of the growing cycle.

	Cl^-	NO_3^-	$H_2PO_4^-$	SO_4^{2-}	Na^+	K^+	Mg^{2+}	Ca^{2+}	Ash
					(g/100 g d.w.)				
Cultivar									
Amadeus	0.7	4.4	0.9	0.6	0.2	5.8	0.2	1.1	17.2
Ronda	0.7	3.7	0.9	0.6	0.2	6.0	0.2	1.1	17.2
Sp. arrangem.-density									
4/0-620 plants/m^2	0.7	4.1	0.9	0.6	0.2	5.8	0.2	1.1	17.0
4/1-316 plants/m^2	0.7	4.2	0.9	0.5	0.2	6.3	0.2	1.1	17.5
8/1-620 plants/m^2	0.7	3.9	0.9	0.6	0.2	5.6	0.2	1.1	17.0
Significance (1)									
Cultivar	ns	ns	ns	ns	ns	ns	ns	ns	ns
Spatial arrangement	ns	ns	ns	ns	ns	ns	ns	ns	ns
Cv.*Sp. arrangement	ns	ns	ns	ns	ns	ns	ns	ns	ns

(1) Significance of F: ns, not significant.

Table 3. Kjeldhal nitrogen, reduced nitrogen and nitrogen use efficiency (NUE) in romaine lettuce leaves as affected by cultivars and spatial arrangement at the end of the growing cycle.

	Kjeldhal N (g/100 g d.w.)	Reduced N (Kjeldhal N %)	NUE (g d.w./g N)
Cultivar			
Amadeus	4.0	75.8	24.8
Ronda	4.2	80.0	23.7
Sp. arrangem.-density			
4/0-620 plants/m^2	4.3	78.0	23.7
4/1-316 plants/m^2	4.3	78.4	23.2
8/1-620 plants/m^2	3.8	77.4	26.1
Significance [(1)]			
Cultivar	ns	ns	ns
Spatial arrangement	ns	ns	ns
Cv.*Sp. arrangement	ns	ns	ns

[(1)] Significance of F: ns, not significant.

Figures

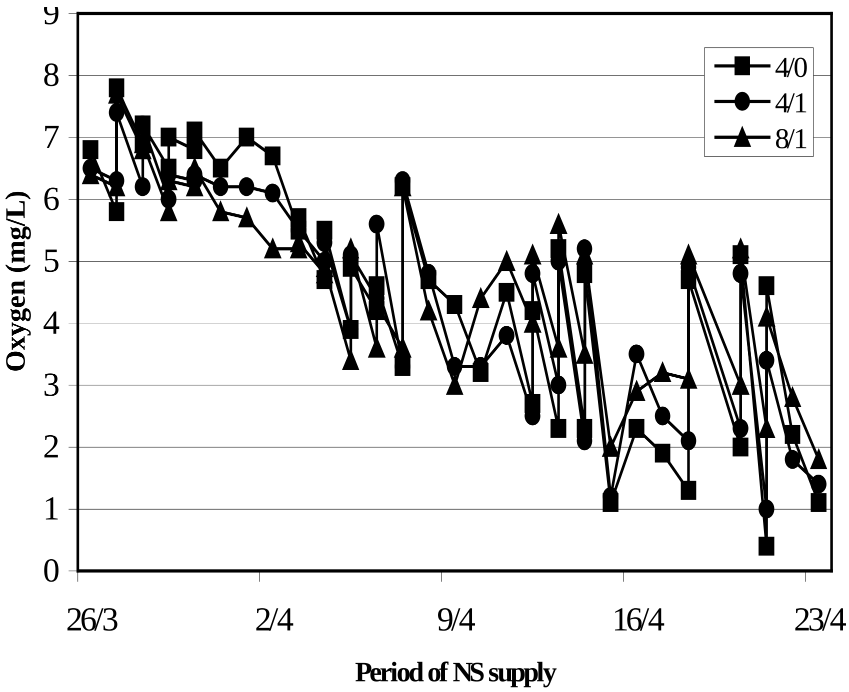

Fig. 1. Oxygen concentration in NS during growing cycle of mini-romaine lettuce in a floating system.