Possibilities for Soilless Cultivation in Cut Chrysanthemum: Effect of Irrigation Frequencies and Spacing Schedules

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Abstract

Three levels of irrigation frequencies, provided by root misting, combined with three plant densities and two spacing treatments were tested to evaluate the optimum conditions during the first crop stages of chrysanthemum in a soilless cultivation system (aeroponics) in an experiment conducted in autumn. The optimum misting frequency was $3 \times 2'$ times $\times$ min h^{-1}. A higher frequency ($12 \times 1'$) had no additional effect, whereas the lowest frequency ($1 \times 6'$) had a negative effect on total shoot dry mass (TDM_s). The highest plant densities (172 and 344 plants m^{-2}) could be used until week 2 with hardly any negative effect on TDM_s, and resulted in higher light interception and higher total shoot dry mass per m^2. During the period between week 2 and 4 after planting, a higher density (172 compared to 86 plants m^{-2}) had a strong negative impact on the TDM_s, while a further increase to 344 plants m^{-2} had only a minor effect. When spacing (week 2) from 344 to 172 plants m^{-2}, TDM_s at week 4 was not negatively affected by the high starting density, though spacing from 172 to 86 plants m^{-2} resulted in a 13% reduced TDM_s, as compared to plants grown at 86 plants m^{-2} continuously. It is concluded that the irrigation frequency until week 4 after planting under these light conditions, should be three times per hour. Furthermore, very high plant densities (e.g., 344 plants m^{-2}) are feasible until week 2 with hardly any negative effects on plant growth, while spacing schemes give several possibilities for a smaller reduction of the TDM_s, than that expected by the higher initial densities.

INTRODUCTION

Most single-harvest greenhouse crops with a short production cycle and a high plant density, e.g., chrysanthemum, are still predominantly grown in soil. Cut chrysanthemum represents one of the most intensive cropping systems in horticulture, with approximately four to five successive crops per unit area annually. Since long, research has focused on development of cost-effective systems to achieve reductions in the environmental impact and improvements in production efficiencies of such intensive cropping systems (Costa and Heuvelink, 2003). Soilless cultivation systems are often used in horticulture because of their high production potential, independence from soil conditions and soil-borne diseases, as well as the possibility of drainage recirculation, which results to reduction of environmental pollution by emission of fertilizers and crop protectants (Costa and Heuvelink, 2003). Furthermore, we expect that by implementing mobile cultivation systems, the manipulation of plant density in different developmental stages of a crop becomes possible.

A successful attempt was made with an almost completely hydroponic ebb-and-flow system, where the substrate (jute plugs) was merely used as support material, and a separate rooting phase was utilized (Buwalda et al., 1994; Buwalda and Kim, 1994). These experiments showed for the first time that production was possible for 10 consecutive chrysanthemum crops almost without substrate. This raises the question if substrate is really necessary, even as support material, and whether it is possible to

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incorporate the rooting phase in the entire production system. The elimination of the substrate would make the production system economically feasible for chrysanthemum, since soilless cultivation has been until now too expensive (in The Netherlands) due to the high costs of renewing the substrate (Buwalda et al., 1994), while incorporation of the rooting phase in the system would eliminate the transplant media and labour related costs (Hansen, 1999). The effect of plant density on chrysanthemum yield and quality characters is well studied (Carvalho and Heuvelink, 2001; Huld and Andersson, 1997) and is closely related to the intensity and quality of the light that passes through the canopy. Higher plant densities reduce light intensity within the crop canopy and alter much of the R-light, while allowing larger amounts of Fr-light to pass through (Heins and Wilkins, 1979). Very high values (e.g., 125 plants m^{-2}) of plant density were found to strongly reduce plant height (Huld and Andersson, 1997), especially when light is limiting (Langton et al., 1999). Furthermore, doubling plant density (from 32 to 64 plants m^{-2}) largely reduced (48%) flower number per plant (Carvalho and Heuvelink, 2001). On the other hand, the sensitivity to plant density for each phase of cultivation may differ, and each phase may affect the succeeding one. However few researchers have attempted to determine the effects of different densities applied at different stages of cropping. In order to enhance the production per m^2 by using different plant densities at different stages while still producing high-quality chrysanthemums, a better understanding of density effects on growth and quality characters is required. The scope of this paper was: i) to test the possibility of merging the rooting phase with the growth phase, ii) to analyze the effect of very high plant densities (up to 344 vs. 64 plants m^{-2} used in commercial practice) during the first stages of cultivation (up to 4 weeks) on crop growth, and iii) to find the misting frequency for optimum growth.

MATERIALS AND METHODS

Experimental Setup

The experiment was carried out in one compartment (15×9.6 m) from a multispan Venlo-type glasshouse (52°N, Bleiswijk, The Netherlands), from 16 October to 16 November 2007 (average outside global radiation 120 W m^{-2}), and repeated from 15 February to 15 March 2008 (average outside global radiation 170 W m^{-2}). Un-rooted cuttings of chrysanthemum 'Reagan Elite White' (Royal van Zanten, Valkenburg, The Netherlands) were placed (free hanging in holes) on grey polyethylene lids (30×40 cm) at 86, 172 and 344 plants per m^2. Plants were irrigated by root spraying (half strength of Hoagland solution; EC 1.0 dS m^{-1}; pH 5.5; 20-25°C). The lids were placed on plastic containers (l×w×h: 30×40×20 cm) on ebb-flow tables. Each container was equipped with one nylon hazy arc sprinkler, which had a spraying capacity of 0.65 L per min at a pressure of 2.5 bar. The sprinklers were placed 5 cm above the bottom of the container. Each pump (Grundfos P5, 2 bar) supplied 6 containers. All the cuttings were rooted under the same conditions (watering frequency of 3×2 times × min/h; relative air humidity (RH) was set at 95%; day and night heating setpoint temperature at 24°C; ventilation temperature set point at 30°C; screening when outside global radiation was higher than 300 W m^{-2}). Rooting was visible on day 6. After the rooting period (i.e., from day 7 onwards), heating and ventilation temperature were adjusted to 20 and 26°C, respectively, RH to 85%, while screening was applied when outside global radiation was higher than 450 W m^{-2}. Starting at week 3 (i.e., from day 15 onwards) the RH was further decreased to 70%. Plants were submitted to long-day (LD) (14 hours/day) conditions. Assimilation light (HPS Philips SON-T Agro, 50 µmol m^{-2} s^{-1} PAR) was applied to the crop to extend and supplement natural daylight. The lamps were switched on when outside global radiation was lower than 150 W m^{-2}, and switched off when outside global radiation was higher than 250 W m^{-2}. After the rooting period, three levels of misting frequencies (12×1, 3×2, and 1×6 times × min/h) were applied to five spacing schedules (86/86, 172/86, 172/172, 344/172, 344/344 plants per m^2; former plant density refers to the period 0 to 2 weeks, while the later refers to the period 2 to 4 weeks), resulting in a total of

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fifteen treatments. This time of reducing the density by spacing was chosen, since soon after the roots intertwined, and spacing would cause root damage.

Destructive Measurements

Plants were destructively harvested on days 0, 14 and 28 after planting. Twelve (densities 86/86 and 172/172 plants m^{-2}, day 14; densities 86/86 and 172/86 plants m^{-2}, day 28) or 24 (density 344/344 plants m^{-2}, day 14; densities 172/172, and 344/172 plants m^{-2}, day 28) or 48 (density 344/344 plants m^{-2}, day 28) plants were sampled. In the destructive measurements the total shoot and root fresh and dry mass of individual plants (TDM$_s$ and TDM$_r$ respectively) (ventilated oven, 105°C for at least 15 h), the number of leaves on the main stem (≥1cm) (=number of internodes, NoI), the stem length and the leaf area (LA) (LI-COR, Model 3100 Area Meter; Lincoln, NE, USA) were recorded.

Statistical Analysis

The experimental set up was a split plot design where the main factor was the watering frequency and spacing scheme the split factor. Data were subjected to analysis of variance (ANOVA), treatment effects were tested at 5% probability level using F-test. The statistical software Genstat 10 was used (VSN International Ltd., Herts, UK).

RESULTS

No interaction was observed between watering frequency and spacing schedule for any of the characters examined, and thus they are presented separately. Both factors had a significant influence on biomass production during the two growth periods, while plant density effect was dominant in terms of mass production per m^2.

Misting Frequency

The effect of misting frequency on total shoot dry mass per m^2 (TDM$_a$; Figs. 1 and 2) and total shoot dry mass per plant (TDM$_s$; Table 1), was similar on day 14 and 28. Two weeks after planting, plants irrigated under frequency 1×6' were significantly lighter (18%) (TDM$_s$) than plants grown under frequency 3×2', which acquired the heaviest plants (0.38g). For TDM$_a$, frequency 3×2' also induced a higher yield per m^2 at week 2, and frequency 1×6' the lowest one (13%). On day 28, plants grown at frequencies 12×1' and 3×2' did not differ significantly neither in TDM$_a$ nor in TDM$_s$, while they were significantly heavier (15%) compared to plants grown at frequency 1×6', which resulted in 12% lower TDM$_a$. On day 14, significantly heavier (TDM$_s$) plants acquired significantly higher total root dry mass per plant (TDM$_r$) too, which resulted in similar root weight ratio (RWR; TDM$_r$/(TDM$_s$+TDM$_r$)) (14.4%) for different water frequencies (differences <2%). In contrast on day 28, the RWR was dependent on the frequency (Fig. 2), where frequency 1×6' acquired the highest one, followed by frequency 3×2'. Moreover, the shoot water content (WC) was significantly decreased in plants grown at frequency 1×6', while the root WC was not affected (data not shown).

For stem length and number of internodes (NoI), significant differences were found between misting frequencies both on day 14 and 28, however these effects were small (max. difference 6%). On the other hand, plants grown at frequency 1×6' showed a strong reduction in LA (Table 1), and thus in LAI (Fig. 1). As in TDM$_s$, frequency 3×2' acquired a significantly higher LA than frequency 12×1' on day 14, while this difference was no longer significant on day 28.

Plant Density

The effect of plant density on total shoot dry mass per plant (TDM$_s$; Table 1) was different during the two crop phases. On day 14, the TDM$_s$ was significantly decreased (9%) by increasing plant density from 86 to 172 plants m^{-2}. A further increase of the density from 172 to 344 plants m^{-2} did not significantly affect the TDM$_s$. On day 28, an increase in plant density from 86 to 172 plants m^{-2} resulted in 38% decrease in TDM$_s$, while a further increase to 344 plants m^{-2} gave a 21% additional decrease. Spacing to half

on day 14, caused a 13% decrease in TDM_s in 172/86 plants m^{-2}, compared to 86/86 plants m^{-2}. To the contrary, the TDM_s in 344/172 plants m^{-2} was not significantly affected, as compared to 172/172 plants m^{-2}. The plant density had a dominant effect on total shoot dry mass per m^2 (TDM_a; Figs. 1 and 2). During the first 2 weeks, doubling the plant density (from 86 to 172 plants m^{-2}) resulted to an 85% increase in TDM_a, while the highest density gave an additional 94% increase. At the end of week 4, a two-fold initial increase in plant density (from 86 to 172 plants m^{-2}) gave a 41% increase in TDM_a, while the highest density (344 plants per m^2) further increased TDM_a by 62%. As in TDM_s, spacement at week 2 resulted in a decrease (13%) in TDM_a at 172/86 plants m^{-2}, as compared to 86/86 plants m^{-2}. On the other hand, there was no significant difference between a plant density of 344/172 and 172/172 plants m^{-2} in TDM_a. Unlike watering frequency, already on day 14 plant density had a strong effect on RWR, which significantly decreased with increasing plant density, a picture which persisted on day 28 too. RWR values did not statistically differ between plants grown in one density and plants reduced to this density on day 14 from a higher one (Fig. 2). Moreover, plant density during growth did not affect either shoot or root WC (data not shown). In stem length the difference between different densities was small (<5%), though statistically significant (Table 1). Moreover, increasing plant density caused a gradual decrease in the number of leaves and the LA. A reduction of plant density from 172 to 86 plants m^{-2} gave the same results as the plant density of 86/86 for the number of leaves and LA. On the other hand statistical differences were observed on these parameters between a decrease in plant density of 344 to 172 and 172/172 plants m^{-2}.

DISCUSSION

In the present experiment, we show that a separate rooting stage is not needed, and that rooting and early growth can take place in one phase in aeroponics. Root formation in chrysanthemum cuttings with root spraying has been reported by Molitor and Fischer (1993), who used relatively short duration (30 s) and relatively long intervals (up to 4 h) between spraying times compared to our setup (mainly focused on growth after rooting). This shows that during the rooting phase further decrease of spraying time might be adequate. According to Hansen (1999), rooting in chrysanthemum was induced in 2.5 weeks with a modified nutrient film technique (NFT), a procedure relatively slow compared to the time reported here (6 days). Incorporation of the rooting in the production system, would give an advantage in logistics and would decrease the production costs. Misting frequency 3×2' induced optimum growth until day 28, though the total amount of water was half compared to 12×1'. In both phases, frequency 1×6' seemed to induce drought stress and negatively affected growth. This can be partly explained by the lower LAI on day 14, due to smaller area of individual leaves, since number of leaves between water frequencies was similar (Table 1). The importance of spraying times and to a lesser extent the total amount of water is also stressed by Molitor and Fischer (1993), who mainly focused on the rooting phase. The misting frequency, besides the light conditions which were low (autumn) in this experiment, also is dependent on the age of the plants.

At the first stages of growth, the partitioning of the plant biomass on the roots (RWR) was the same between different frequencies, though at the end of week 4 a reduction in the amount of water (from 12×1' to 3×2') resulted in an increase of the RWR, while an additional decrease in the spraying times (from 3×2' to 1×6') gave a further increase in the amount of plant biomass relocated to the roots. So, the RWR seems to be an indication of the history of the plant water status during the second crop phase, in agreement with previous work (Sangakkara et al., 2000).

Using different plant densities in combination with different temperatures (Carvalho et al., 2005; Ploeg, 2007) at different crop stages, a possibility of the mobile cultivation systems, arises a lot of opportunities to enhance production per m^2 and increase energy efficiency of greenhouse chrysanthemum cultivation. We show here till day 14, very high plant densities (344 plants m^{-2}) are feasible, with a small cost (9%) in

TDM_s, but with a big advantage in production per m^2 (180%). In these early stages, light is not a limiting factor (mutual shading), and higher plant densities are advantageous, because of the very fast canopy closure (LAI>2, Fig. 1). The higher the plant density at this stage, the lower the partitioning of the total plant biomass to the roots, which was not found to have a negative effect on TDM_s at the next crop phase (spacement from 344 to 172 plants m^{-2} did not cause decrease in TDM_s as compared to 172/172 plants m^{-2}). On day 28, plant density had a strong negative impact on TDM_s, while higher densities were always advantageous in terms of yield per m^2. The counteractive effects of plant density on the TDM_s and TDM_a ask for a need of knowing the optimum between the decrease of the former, and its effect on visual quality characteristics, and the increase of the latter. Moreover, further research needs to define what could be the density of the later crop stages, and to which extent this would affect the relation between TDM_s and TDM_a. On day 28, spacement treatment resulted in a slight (13%; 177/86 plants m^{-2}) or no decrease (344/172 plants m^{-2}) of the TDM_s, which arises the possibility that lowering the density at the next crop phase can eliminate or mitigate to a high extent the negative effect of high plant density in the previous phase. The present experiment is limited till 4 weeks after planting, and a more detailed study is needed where the plants will be grown until commercial harvestable stage.

The RWR was found to be an indicator of the plant density in both crop phases, which confirms previous findings (Brouwer, 1983; Demotes-Mainard and Pellerin, 1992). Moreover, this ratio was not constant, but it adapted to the new conditions (the ratio is adjusted to the values of the new density after spacement).

CONCLUSION

When grown aeroponically, no separate rooting phase is needed. The watering frequency 3×2', under light conditions of 120 W m^{-2} per day, was found to be adequate for optimum growth until day 28. Densities up to 344 plants m^{-2} can be used until day 14, while in the next crop phase spacing to lower densities causes a slight or no decrease in the TDM_s, compared to plants continuously grown under the lower densities. Further work is needed to examine the effects of the reduced TDM_s on dry mass at flowering, and to find the optimum balance in soilless cultivation of chrysanthemum, based on the market demands, between the increase in TDM_a and the decrease in TDM_s.

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Tables

Table 1. The effect of misting frequency and spacing schedules on days 14 and 28 after planting on total shoot dry mass (TDM_s), total root dry mass (TDM_r), stem length, number of internodes (NoI), and leaf area (LA) per plant. Different letters within columns and treatments indicate differences between treatments based on LSD at 5% level.

	TDM_s (g plant^{-1})	TDM_r (g plant^{-1})	Stem length (cm)	NoI (no. plant^{-1})	LA (cm^2)
			Day 14		
Frequency (times × min h^{-1})					
1×6'	0.31^a	0.052^a	14.0^c	7.1^a	58.4^a
3×2'	0.38^c	0.065^c	13.6^b	7.6^b	82.0^c
12×1'	0.34^b	0.059^b	12.6^a	7.4^b	75.5^b
$F_{pr}{}^x$	*<0.001*	*<0.001*	*<0.001*	*0.010*	*<0.001*
			Day 28		
1×6'	1.49^a	0.250^b	33.5^b	14.5^a	341^a
3×2'	1.71^b	0.242^b	34.1^c	15.2^b	425^b
12×1'	1.67^b	0.213^a	32.3^a	14.4^a	404^b
$F_{pr}{}^x$	*<0.001*	*0.007*	*<0.001*	*<0.001*	*<0.001*
			Day 14		
Density (pl m^{-2}) ^{y}					
86/86	0.37^b	0.070^c	13.1^a	7.6	75.7^b
172/172	0.34^a	0.059^b	13.3^a	7.4	71.9^{ab}
344/172	0.33^a	0.046^a	13.8^b	7.2	68.3^a
$F_{pr}{}^x$	*0.006*	*<0.001*	*<0.001*	*0.077*	*0.026*
			Day 28		
86/86	2.05^d	0.328^d	33.3^b	15.8^d	484^d
172/86	1.82^c	0.288^c	32.4^a	14.7^c	435^c
172/172	1.49^b	0.193^b	34.6^d	14.6^{bc}	360^b
344/172	1.54^b	0.22^b	32.3^a	14.3^{ab}	372^b
344/344	1.23^a	0.146^a	33.8^c	13.9^a	301^a
$F_{pr}{}^x$	*<0.001*	*<0.001*	*<0.001*	*<0.001*	*<0.001*

[x] F probability; significant levels *<0.05* presented in bold type.
[y] The former plant density refers to the period 0 to 2 weeks, while the later refers to the period 2 to 4 weeks after planting.
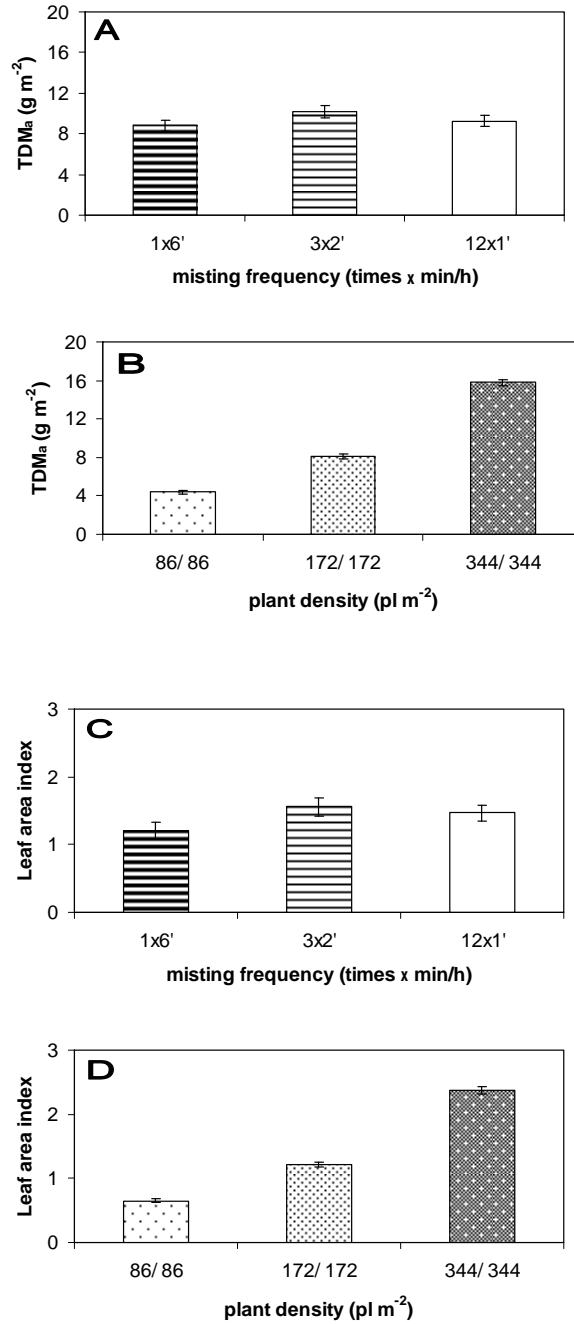
Fig. 1. The effect of misting frequency (A, C) and spacing schedules (B, D; the former plant density refers to the period 0 to 2 weeks, while the later refers to the period 2 to 4 weeks after planting) on total dry mass per m^2 (TDM_a) and leaf area index on day 14.
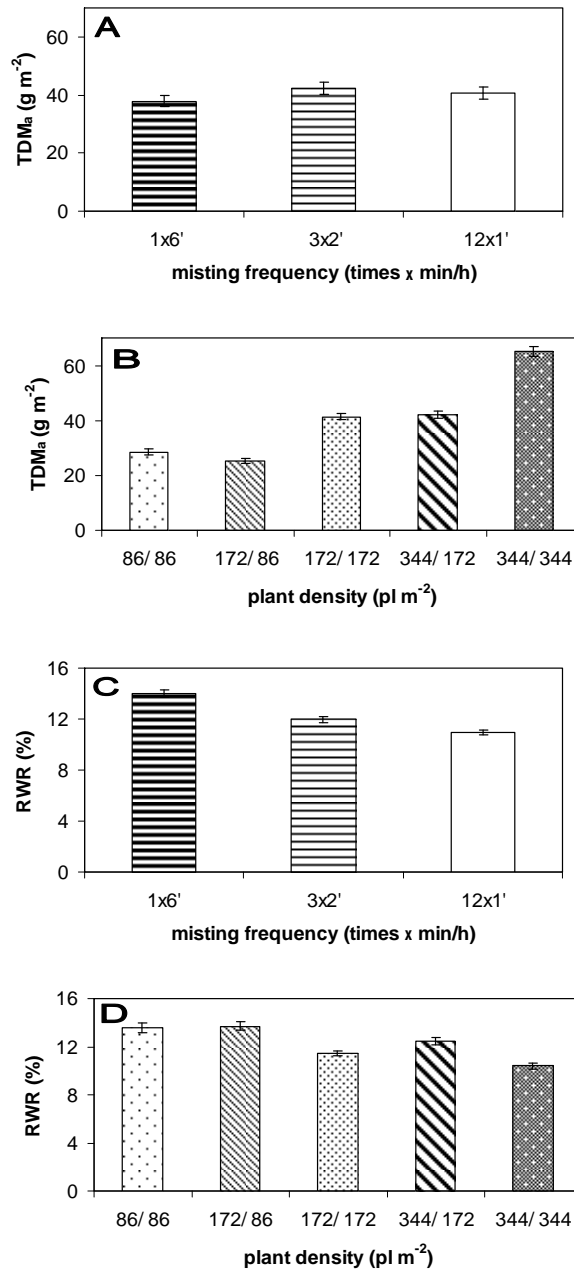
Fig. 2. The effect of misting frequency (A, C) and spacing schedules (B, D; the former plant density refers to the period 0 to 2 weeks, while the later refers to the period 2 to 4 weeks after planting) on total dry mass per m^2 (TDM$_a$) and partitioning to the roots (RWR) on day 28.