Scientia Horticulturae 123 (2009) 204–209

Contents lists available at ScienceDirect

Scientia Horticulturae

journal homepage: www.elsevier.com/locate/scihorti

Interaction of short day and timing of nitrogen fertilization on growth and flowering of 'Korona' strawberry (*Fragaria* × *ananassa* Duch.)

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ARTICLE INFO

Article history:
Received 20 February 2009
Received in revised form 8 July 2009
Accepted 14 August 2009

Keywords:
Flowering
Fragaria
Growth
Photoperiod
Strawberry
Timing of N fertilization

ABSTRACT

The effects of timing of nitrogen (N) fertilization relative to the beginning of a 4-week floral-inducing short-day (SD) period have been studied in 'Korona' strawberry plants under controlled environment conditions. Groups of low fertility plants were fertilized with 100 ml of calcium nitrate solution for 3 days a week for a period of 3 weeks starting at various times before and at the beginning of the SD period, as well as at different times during the SD period. All plants, including SD and long day (LD) control plants, received a weekly fertilization with a low concentration complete fertilizer solution throughout the experiment. Leaf area, fresh and dry matter increments of leaves, crowns and roots, as well as leaf chlorophyll concentration (SPAD values) were monitored during the experimental period. A general enhancement of growth took place at all times of N fertilization. This was paralleled by an increase in leaf chlorophyll concentration, indicating that the control plants were in a mild state of N deficiency. When N fertilization was started 2 weeks before beginning of the SD period, flowering was delayed by 7 days, and this was gradually changed to an advancement of 8 days when the same treatment was started 3 weeks after the first SD. The amount of flowering was generally increased by N fertilization although the effect varied greatly with the time of N application. The greatest flowering enhancement occurred when N fertilization started 1 week after the first SD when the number of flowering crowns and the number of inflorescences per plant were more than doubled compared with the SD control, while fertilization 2 weeks before SD had no significant effect on these parameters. Importantly, the total number of crowns per plant was not affected by N fertilization at any time, indicating that enhancement of flowering was not due to an increase in potential inflorescence sites. No flowering took place in the control plants in LD. Possible physiological mechanisms involved and practical applications of the findings are discussed.

1. Introduction

The June-bearing strawberry is a quantitative or facultative short-day (SD) plant that initiates flowers under SD conditions at temperatures ranging from about 15 to 25 °C (Guttridge, 1985; Taylor, 2002). At higher temperatures flowering is increasingly inhibited also under SD conditions (Verheul et al., 2006, 2007). However, because of a pronounced interaction of photoperiod and temperature, floral initiation also takes place in many cultivars even in 24-h long days (LD) if the temperature is below about 15 °C (Ito and Saito, 1962; Heide, 1977).

Flowering of strawberry may also be modified by the plant's water regime and nutrient status, especially nitrogen (N) status. However, as stated by Guttridge (1985), the nutritional effects on flowering in strawberry are complex. While growth-stimulating doses of mineral nutrients tend to inhibit floral initiation *per se*, the number of inflorescences may be increased indirectly if the dominant response to nutrition is to increase the number of crowns and thereby the number of potential inflorescence sites (Abbott, 1968; Breen and Martin, 1981). These opposing effects are problematic to resolve and are seldom analysed in the literature on strawberry nutrition. Increasing the nutrient supply from a low base will generally increase flowering (Breen and Martin, 1981) and fruit yields (Lineberry et al., 1944), but too much, especially of nitrogen, can inhibit flower formation and reduce fruit yield (Whitehouse, 1928; Lineberry et al., 1944). However, withholding nitrogen and phosphorus may not increase flowering (Abbott, 1968). Extra nitrogen has been reported to reduce summer flower initiation for the autumn crop of a double-cropping cultivar in England, but had little influence on spring flowering (Way and White, 1968).

An important aspect of the fertilization/flowering complex is the question of timing of fertilization relative to the flower-inducing SD period. An early investigation by Long (1939)

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doi:10.1016/j.scienta.2009.08.009

demonstrated that the fertility level during the period of flower bud initiation was important for rich flower formation. Fertilization in the following spring was not equally effective. Similar results were reported by Opstad and Sønsteby (2008). Lieten (2002) varied the fertility level of 'Elsanta' strawberry during various periods of late summer and autumn, and observed large effects on crown size as well as flowering and fruit yield. Potted plants were raised outdoors until the first week of December, cold stored and cropped in a greenhouse. In 2 out of 3 years the highest flower numbers and fruit yields were obtained when nutrition was withheld until the end of August, followed by feeding with a complete fertilizer solution throughout September–November. Withholding nutrition beyond mid-September significantly reduced flowering and yield, as did also fertilization during the month of August.

By varying the time of N fertilization with ammonium nitrate in the ornamental SD plant *Kalanchoë blossfeldiana*, Rünger (1961) demonstrated that while application before the start of SD reduced and delayed flowering significantly, the same applications during the early part of the SD period had the opposite effect and increased flowering. The experiment was started with plants in a mild state of N deficiency. The earlier the application and the larger the amount of N applied, the stronger was the inhibitory effect on flowering. The strongest promotion of flowering resulted when N fertilization was started at the first day of the SD period. The strength of the inhibitory effect of N application prior to SD exposure was enhanced by high temperature during the same period.

Protected cultivation of strawberry for extended marketing season has been increasing worldwide (Wagstaffe and Battey, 2007). This type of intensive production requires high input investments, and accordingly, high yields are therefore required to make the production profitable. Production of quality plants with rich flowering and high yield potential is of particular importance in such a production system. As discussed above, timing and rate of fertilization during the floral induction period can be important in this connection. In order to provide additional information on this issue, we have carried out a controlled environment experiment with the strawberry cultivar Korona in which additional nitrogen was supplied at different periods before and during a 4-week flower-inducing SD period. The results are reported here.

2. Materials and methods

2.1. Plant material and cultivation

Runner plants were collected in the field in mid-July and rooted in 12 cm plastic pots filled with a peat-based potting compost. During rooting and early growth the plants were held in a greenhouse maintained at minimum 20 °C under natural LD summer conditions (18–21-h), until the 4-leaf stage when the experimental treatments were started on August 4. From this stage onwards and throughout the experiment, the plants were grown in daylight compartments of the Ås phytotron at a constant temperature of 18 ± 1 °C and light conditions as described by Sønsteby and Heide (2008). During the same period all plants were fed weekly with 100 ml of a compound fertilizer solution (1.0 g l^{-1} of Superba™ Rød from Yara International (85 mg N l^{-1})) applied to the pots at the first day of the week. From August 19 to September 16 the plants were exposed to 10-h SD for 4 weeks for floral induction. Starting at various times before and during this SD period, groups of plants were given an extra nitrogen supply for three consecutive weeks as shown in Table 1. Control groups in SD and LD received no extra nitrogen (Table 1). During the 3 weeks of N application the treated plants received a daily dose of 100 ml of calcium nitrate solution (7.0 g l^{-1} of Calcinit™ from Yara International (1085 mg N l^{-1})) for 3 days (Tuesday through Thursday), while they received 100 ml of tap water daily for the remaining 3 days of the week. Outside the N feeding periods the plants received 100 ml of tap water daily for 6 days a week throughout the experiment (100 ml of Superba solution on one day). A volume of 100 ml of liquid was adequate to saturate the entire pot soil volume and produce a net run-off of excessive solution.

2.2. Experimental design, data observation and analyses

The experiment was a fully factorial design with three replications consisting of three plants each. Starting 2 weeks before commencement of the SD period and lasting until 2 weeks after its termination, samples of 3×3 plants were harvested as shown in Table 1 for monitoring of fresh and dry weights, chlorophyll content, etc. At harvest the plants were partitioned into three components: green leaves (leaves), stem (crowns), and roots. Roots were washed clean of soil material and, after blotting on tissue paper, fresh weight was determined for each component. Leaf area was measured with a LI-COR Inc. Model LI 3100 area meter, and dry weight was determined after drying at 70 °C. At each harvest chlorophyll concentration of the leaves was assessed by light transmission at 650 nm using a Minolta SPAD-502 hand-held leaf chlorophyll meter (Wood et al., 1993; Markwell et al., 1995). SPAD values were determined on three leaves of each plant.

In each treatment group nine plants remained throughout the experiment for recording of flowering. In these plants new runners were recorded and removed weekly, the time of flowering (first anthesis) was recorded in each plant, and the number of crowns, number of inflorescences, and the total number of flowers in each plant were recorded when all flower buds were well developed and the experiment was terminated.

Experimental data were subjected to analysis of variance (ANOVA) by standard procedures using a MiniTab® Statistical Software program package (Release 14; Minitab Inc., State College, PA, USA).

Table 1
Calendar of treatments showing the timing of N fertilization and plant sampling relative to the 4-week flower-inducing SD period. On weeks marked with X the respective groups of plants received an extra N fertilization for 3 days weekly, starting on the date indicated. Likewise, sampling of plants for determination of fresh and dry weight, chemical contents, etc., were performed on the days marked with an asterisk (*).

Start of N fertilization, weeks from beginning of SD	Week number and date								
	32, 5/8	33, 12/8	34, 19/8	35, 26/8	36, 2/9	37, 9/9	38, 16/9	39, 23/9	40, 30/9
−2	X*	X*	X*	*	*		*		
−1		X*	X*	X	*		*		
0			X*	X*	X	*			
1				X*	X*	X		*	
2					X*	X*	X	*	
3						X*	X*	X	*
SD control (−N)			*	*	*	*	*		
LD control (−N)	*	*	*	*	*	*	*		