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Relationship between Rhizome Temperatures and Shoot Temperatures for Floral Initiation and Cut Flower Production of *Alstroemeria* 'Regina'

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Abstract. **When *Alstroemeria* 'Regina' shoots were grown in a continuous 13°C air temperature, and the underground structures (rhizomes and roots) were placed in a 5°, 10°, 15°, 20°, or 25° water bath, plants produced 22%, 33%, 13%, 14%, or 5% generative shoots, respectively (Expt. 1). When the underground structures were grown at 13°, there were no differences in percentages of generative shoots, regardless if shoots were in a 13° or 21° air temperature, and regardless if shoots were under short or long photoperiods. When soil temperature was 21° and air temperature was 13°, 12% generative shoots were produced only with a night interruption photoperiod (Expt. 2). Data from these 2 experiments led us to conclude that floral induction was controlled primarily by temperatures to which the underground structures were subjected, regardless of the air temperature or photoperiod. Storage root and rhizome dry weights were promoted by 13° air, 13° soil temperatures and night interruptions with incandescent light. Treatments which had a high percentage of generative shoots also had high root and rhizome dry weights.**

The exact control mechanisms for *Alstroemeria* 'Regina' flower induction, initiation, and development are not clearly understood (4, 5, 6, 7, 8). Several workers have shown the influence of air temperature on generative alstroemeria shoot induction and subsequent shoot and flower development (3, 5, 6, 7, 9, 10, 14). Work in Norway by Moum and Strömme (13) showed that air temperatures above 21°C reduced the flowering response of *Alstroemeria* 'Regina' and 'Orchid'. Work in Aalsmeer, The Netherlands, by Vonk Noordgraaf, (14) showed that with 'Walter Fleming', [syn. 'Orchid' (1)], an air temperature above 21° in conjunction with short days or with 25° and 16-hr days inhibited flowering. Vonk Noordegraaf further showed that a 25° soil temperature, in combination with a 9°, 17°, or 25° air temperature reduced the number of generative shoots (4).

Light treatments (photoperiodic and photosynthetic) have been reported to hasten generative (flowering) shoot development of alstroemeria (4, 8, 10, 12, 14). Long days, either as a night-interruption or as a day-continuation of 13- to 16-hr, depending on cultivar, accelerated flowering (4, 8, 10, 12). Generative shoot development ceased during high temperature periods and failed to respond to any light treatment (3, 4, 6, 7, 8, 9, 10).

If *Alstroemeria* cultivars are to continue to become an important cut flower crop in commercial floriculture, it is necessary to determine the control mechanism for flower control, the means to promote continuous flowering and ways to control dates of production. Cooper (2) and Wilkins et al. (16) have shown several growth responses to be affected by soil temperatures. Objectives of these experiments were to investigate the interactions of soil and air temperature and photoperiod on generative shoot development and production in *Alstroemeria* 'Regina' plants.

Materials and Methods

Expt. 1. Alstroemeria 'Regina' plants were divided on 1 Aug. into single rhizomes with attached storage roots and vegetative shoots. Each division was planted in a 15-cm plastic pot filled with 1 peat : 1 perlite : 1 soil (by volume) medium and grown in a glasshouse at a minimum day/night 13°C air temperature under natural-day conditions (45° north parallel) until 1 Jan., when plants were shifted into 28-cm plastic pots using the same medium. From 1 Jan. to 29 Dec., soil temperature treatments of 5°, 10°, 15°, 20°, or 25° (± 1°) were maintained by a specially designed waterbath (Fig. 1) by either cooling or heating the water circulating around the pots. Soil temperatures were monitored continuously. The 4 pots per treatment were covered with 2 sheets of 6 mil plastic before immersion to prevent waterlogging of the root system. The air temperature was a constant 13° until the day temperature could no longer be maintained, even with the use of fan and pad cooling. A 6-cm mulch of shredded polystyrene was used to cover the surface of all pots to reduce soil temperature fluctuations. Control plants were grown on an adjacent greenhouse bench at a constant 13° air temperature.

Expt. 2. Individual plants of *Alstroemeria* 'Regina' were divided on 10 Oct., using a similar medium and pot size as in Expt. 1 and were grown in a 21°C air temperature under natural days until 5 Jan., when they were shifted into 28-cm pots and placed into the temperature-controlled water baths as described

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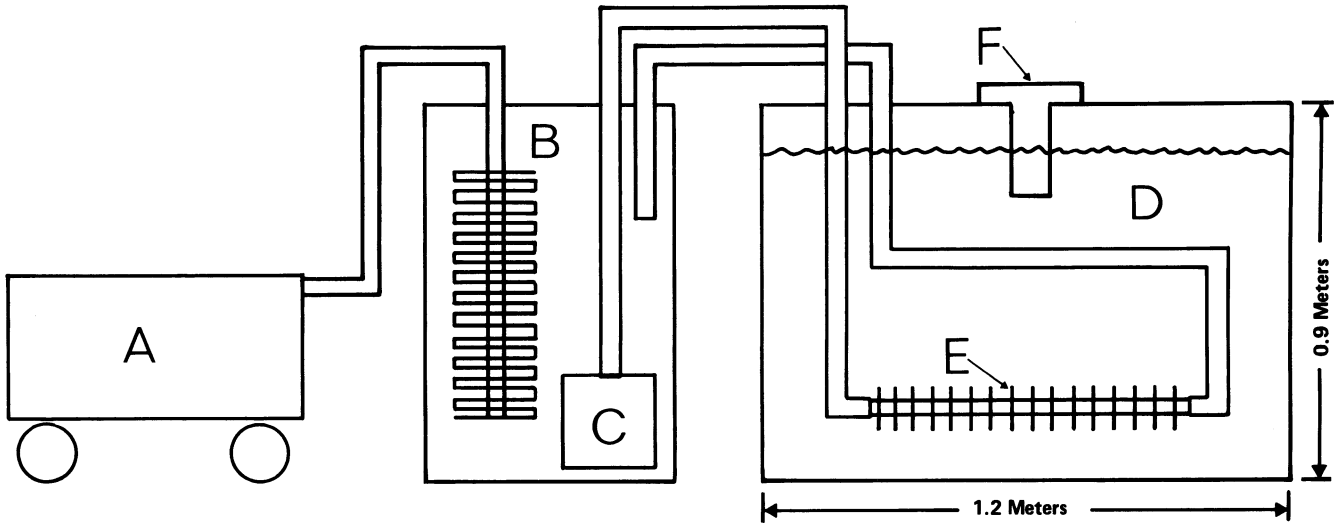

Fig. 1. Schematic of temperature controlled water baths used to maintain soil temperatures. **A)** Portable refrigeration compressor with 1.2 m coil (manufactured by Blue M Co.); **B)** Cooling stock tank, filled with 151 liters of 1:1 (by volume) polyethylene glycol water solution; **C)** one-third horsepower pump that circulates coolant solution to tank as demanded by thermostat control in individual tank; **D)** 1.2 × 1.2 × 0.9 m insulated plywood box, lined with 12 mil polyethylene plastic and filled with 1380 liters of water; **E)** "Fin" tubing through which anti-freeze solution circulates; **F)** 750 W thermostatically controlled heating coil.

Table 1. Growth responses of *Alstroemeria* 'Regina' after plants were grown for one-year in controlled soil temperature chambers in a glasshouse maintained at a minimum 13°C day/night air temperature. (Expt. 1)

Soil temperature (°C)	Total shoot production	Generative shoots (%)	Nodes formed on generative shoots (no.)
5°	179.8	21.9	23.2
10°	202.5	33.3	23.1
15°	242.3	13.4	26.3
20°	253.5	13.7	33.7
25°	312.3	5.4	32.7
Control[z]	289.5	18.1	23.4
HSD[y]	77.8	8.5	4.7

Correlations with soil temperatures

Parameter	R^2
Total shoot production	0.68
Percentage of shoots generative	−0.55
Number of nodes formed on generative shoots	0.74

[z]Plants in a glasshouse at a constant 13°C air temperature.
[y]Honestly significant difference at 5%.

in Expt. 1 (Fig. 1). The temperature treatments consisted of 4 plants per treatment in a factorial combination of a constant 13° or 21° air temperature or soil temperature. Control plants were grown on an adjacent bench in the respective 13° or 21° air temperatures. This experiment continued for 12 months.

In Expt. 2, plants in the 13° or 21°C temperature treatments were placed under either a short-day (0800 to 1600 HR) or an incandescent night-interruption (10 W from 2200 to 0200 HR). The night-interruption treatment was discontinued when the natural daylength exceeded 13.5 hr (1 May).

In Expt. 1 and 2, vegetative shoots were removed monthly (9), and when flowering commenced the number of shoots was recorded. Fertilizer applications were based on weekly soil tests. Monthly fungicide drenches were applied to prevent root diseases.

The temperature treatments in Expt. 1 and 2 were randomized. Differences between treatments were determined using analysis of variance with mean separation by Tukey's honest significant differences. Stems were harvested when the primary flowers opened. The datum termed "days to first harvest" was based on the number of days between the date the experiments commenced and the date the 3rd generative shoot was harvested. We have observed that after the 3rd flowering shoot has been harvested, all subsequent shoots are generative. The "percentage of weeks in production" was calculated from "day to first harvest" to the end of flowering or the end of the respective experiments. The number of nodes and the stem length of each generative shoot were recorded from the base of the umbel to the soil line. In Expt. 1, visual observations were made on rhizome and storage root growth, and in Expt. 2 the storage roots plus rhizome were oven-dried at 75°C for 2 weeks and then weighed.

Results and Discussion

Experiment 1. *Shoot production (total and percentage of generative).* Total shoot number was related directly to increasing soil temperature, whereas the percentage of the shoots which were generative (percentage of generative) was inversely related (Table 1). The 5° and 10°C soil temperature treatments reduced total shoot formation compared to 25° soil temperature; yet, these treatments had the highest flower yields.

In the 5° and 10°C soil treatments (Table 1), generative shoots represent the shoots formed prior to and during the respective temperature tank treatment, as plants had been growing at an inductive temperature (13°) from 1 Aug. to 1 Jan., when the experiment began. With the 15°, 20°, and 25° soil treatments, generative shoot production represents flower production from sites along the rhizome due to the prior 13° treatment, as shoot production from the rhizome reverted to the vegetative condition once plants were placed in the 15°, 20°, or 25° soil treatments. This reversion was no doubt more rapid at 25° vs. 20° or 15°. The increase in total shoot production at 25° represents a net

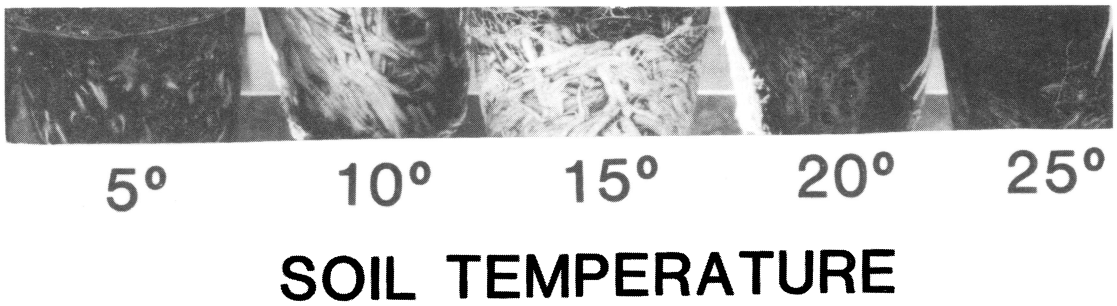

Fig. 2. Effect of soil temperature on storage root development of *Alstroemeria* 'Regina' (Expt. 1) when grown at a minimum air temperatures of 13°C.

Table 2. Influence of inductive (13°C) or noninductive (21°) air or soil temperature treatments and an 8-hr short-day (SD) or night interruption (NI) on growth and flower production of *Alstroemeria* 'Regina' plants after one year (Expt. 2).

Air temp.	Soil temp.	Photoperiod	Shoot production: Total shoots	Shoot production: Shoots generative (%)	Shoot production: Weeks in production (%)	Storage root and rhizome, dry wt. (g)
13°	Ambient	SD	146	30.0	36	107
		NI	100	30.7	39	118
13°	13°	SD	101	30.3	41	127
		NI	65	48.1	44	135
13°	21°	SD	99	0.0	0	35
		NI	93	12.0	34	136
21°	Ambient	SD	133	0.0	0	13
		NI	117	0.0	0	24
21°	13°	SD	88	21.4	43	98
		NI	92	36.1	44	125
21°	21°	SD	123	0.0	0	13
		NI	94	0.0	0	11
Source of variation						
Air temperature (A)			NS	NS	**	
Soil temperature (S)			**	*	**	
Photoperiod (P)			*	NS	**	
Interactions of A, S, P			NS	NS	NS	
HSD (5%)			19	8.6	15	

NS,*,**Not significant or significant at 0.05 or 0.01 levels, respectively.

increase in vegetative shoot production once generative shoot development ceased at this temperature.

After 12 months, plants in the 5° and 10°C soil temperature treatments were still generative, whereas those at 15° or higher temperatures, were vegetative and flowering had ceased. The percentage of generative shoot of the control (ambient soil temperature treatment) plants was midway between the 10° and 15° soil treatment response. This value was expected, as the ambient air temperature was 13° when the greenhouse temperature could be controlled.

We have concluded that once the rhizome of an *Alstroemeria* 'Regina' plant is cold treated (induced) and the plant begins to flower, flowering continues indefinitely, or at least for 1 year, until the rhizome is exposed to temperatures near 15°C or higher (Tables 1, 4).

Number of nodes. The number of nodes formed on a generative shoot increased as the soil temperature increased (Table 1). Plants grown at 5° or 10°C soil temperatures averaged 23 nodes, whereas plants grown at temperatures greater than 20° averaged 33 nodes. Thus, as soil temperature increased, there was a delay in floral initiation as more nodes were formed. The control plants had a similar number of nodes as those plants grown at 5° or 10° soil temperatures.

Storage root development. There were visual differences in the mass and type of storage root formation (Fig. 2) at the termination of Expt. 1. Plants whose root systems were in 10° or 15°C soil temperatures had larger and greater numbers of storage roots when compared to root systems in 20° or 25° temperatures (composed mainly of fibrous roots). Plant grown at 5° had reduced root systems.

Experiment 2. *Shoot production (total and percentage of generative)*. There was no influence of 13° or 21°C air temperatures on total shoot formation or on the percentage of generative shoots (Table 2). Soil temperature and photoperiod influenced total shoot production while soil temperature had the greatest effect on the percentage of generative shoots. Plants grown at 21° air/21° soil temperature produced a greater total number of shoots than at 13° air/13° soil temperature. This trend is similar to that observed in Expt. 1 (Table 1). The percentage of the shoots that were generative again was dependent on soil

temperature (Table 2). All plants grown at 13° soil temperature flowered, regardless of air temperature or photoperiod.

It is interesting that 12% of total shoot production was generative at a 21° soil/13° air temperature. This treatment should not have promoted flowering. The 12% generative response no doubt was related to the night-interruption light treatment and a 13° air temperature. Vonk Noordegraaf (15), using 'Walter Fleming', observed a similar response with the 21°C soil/cool air temperature plus night-interruption combination. Increased storage root dry weight also occurred at a 13° air/21° soil temperature. We feel this increased accumulation at 13° air/21° soil temperature under night-interruption treatment occurred concomitant with generative shoot formation. Further work is needed to determine if a 13° air temperature and/or various light intensities or photoperiods could reduce the impact of a 21° rhizome/soil temperature.

Percentage of weeks in production. The percentage of weeks in production over the course of the 12-month long experiment was increased by the 13°C soil temperature (Table 2). A night-interruption promoted up to a 5 percentage point increase in the duration of flowering. Maintaining soil temperatures at 13° also resulted in a 5 percentage point increase in the duration of flowering compared to ambient soil temperatures. Others (6, 9, 10) have stated that the earlier onset of production, the greater the potential yields. Therefore, soil temperature control is critical for long-term production.

Rhizome and storage root dry weight. Rhizome and storage root dry-weights were influenced by air and soil temperature and photoperiod (Table 2). A 13°C soil temperature treatment, regardless of air temperature, with night-interruptions, resulted in the maximum rhizome and storage root dry-weight. Plants grown at 21° air temperature consistently had low rhizome and storage root dry-weights. Plants grown under short-days produced lower rhizome and storage root dry-weights than plants grown with a night-interruption. The exception was with plants in the 21° soil/21° air temperature treatment, where the dry-weights for night-interruption and short-day treatments were similar, but low. There appears to be a relationship between percentage of generative shoots and high rhizome and storage root dry-weight accumulation. This is an area that needs further examination.

Although researchers have investigated the effect of alternating temperatures (10, 15), constant low air temperatures (4, 5, 7, 13, 14, 15), or high air temperatures (4, 5, 8, 13, 14) on growth and flowering of alstroemeria, no one yet has shown a definite relationship between controlled soil temperature and floral induction (Table 1) or soil/air temperature × photoperiod with flower induction and generative shoot production of *Alstroemeria* 'Regina' (Table 2). Lin (11) reported that circulating 10°C tap water in pipes 25 cm below the soil surface increased spring-summer production, and a 16-hr high-pressure sodium lighting regime reduced flowering. Our research (Tables 1, 2) clearly shows that a soil temperature between 10° to 13° positively influences generative shoot production and is critical for continued long-term flower production, regardless of air temperature or photoperiod (Table 2). We also suggest that the floral induction of *Alstroemeria* 'Regina' occurs in the rhizomes and requires a continuous low temperature induction treatment as the "induction" is not a singular event on the rhizome, but a continuous process for each shoot as the rhizome elongates.

The process was evident (Table 1) from the influence of a previous inductive 13°C temperature prior to a range of inductive or noninductive soil temperatures. Additional support for the rhizome or storage roots as the site of perception for floral induction was seen in Expt. 2 (Table 2), when plants were grown at noninductive temperatures (21°) for 3 months prior to being placed in various inductive or noninductive air/soil temperature treatments for 12 months. Plants in the 21° air/21° ambient temperature had been under treatment for 15 months. However, a night-interruption concomitant with a 13° air and 21° soil temperature (Table 2) is an exception, as discussed.

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