The Danish Institute of Plant and Soil Science
Research Center for Horticulture
Department of Horticultural Engineering
DK-5792 Aarslev

Beretning nr. 2246

Negative DIF: The effect of temperature drop prior to light period on environment and energy consumption under long day conditions in greenhouses (II)

Negativ DIF: Virkningen af temperaturfald før lysperioden på klima og energiforbrug under langdagsforhold i væksthuse (II)

MARIUS G. AMSEN & OTTO FRØSIG NIELSEN

Summary

From February to April 1991 an experiment with long day plants (18 hours) in greenhouses was carried out. The effect of a traditional room temperature programme with fixed room temperature set points day/night (18°/18°C) was compared with the effects of a negative DIF day/night (14°/22°C) programme with a mean room temperature control. In the light period supplementary light was applied whenever outside irradiation was less than 40 μmol/m^{2}s. To preserve energy and to promote a longer period with low room temperature the room temperature was reduced one hour prior to light period.

High priority of negative DIF implicates ventilation of warm air at sunrise to promote a fast decrease in room temperature. By applying the room temperature reduction prior to light period advantage could be taken of the cold night situation and ventilation avoided.

The mean room temperature control, which preferably regained a lack in room temperature during the dark period when the greenhouse is insulated, may also help to preserve energy. However, in spite of this an increase of energy consumption of 4 per cent was found, compared to the traditional temperature programme.

Key words: Greenhouses, district heating, mean room temperature control, programme call, computer control, long day, negative DIF.

Resumé

Fra februar til april 1991 blev der udført et forsøg med dyrkning af langdagsplanter, 18 timer dag, hvor virkningen af 2 rumtemperaturstyringsprogrammer undersøgtes: et traditionelt med faste setpunkter for rumtemperaturen dag/nat (18°/18°C) sammenlignedes med et negativ DIF dag/nat (14°/22°C) kombineret med gennemsnitstemperaturstyring over hele forsøgsperioden. I lysperioden anvendtes tilskudslys, når lysintensiteten ude var mindre end 40 μmol/m^{2}s. Tilskudslys af højtryksnatriumlamper med en installeret effekt på 30 W/m^2 og målt til 40 μmol/m^{2}s i plantehøjde. En time før daggry sænkedes rumtemperaturen fra det høje natniveau 22°C til 14°C.

Høj prioritering af negativ DIF, der medfører udluftning af varm luft ved solopgang for at tvinge rumtemperaturen ned, medførte 4% højere energiforbrug end et traditionelt temperaturprogram.

Anvendelse af middeltemperaturregulering, der fortrinsvis sætter varme på i de perioder, hvor gardiner er trukket for, har ikke kunnet forhindre det højere energiforbrug.

Nøgleord: Væksthusopvarmning, fjernvarme, middeltemperaturstyring, modulkald, computerstyring, langdag, belysning, negativ DIF.

Introduction

This experiment should be seen in connection with the previous experiment (13) where similar questions under short day conditions were investigated.

The specific topics reviewed in this experiment may be summarized as follows:
- avoiding energy consumption peaks in morning and evening hours.
- negative DIF room temperature programme.
- preserving energy by reducing room temperature prior to light period.
- move energy consumption to night periods by average mean temperature control.
- supplementary light application dependent on low electricity tax periods.

If a combination of those conditions into one single temperature control routine is possible, it will make it attractive for growers to apply negative DIF at a minimum of expenses. This was a main target of the experiment. However, the long day conditions in contrast to short day conditions left us with a very short night period which can be used to correct the mean room temperature.

In general a reduction of energy consumption peaks in greenhouses can be obtained with high night room temperature and low day room temperature set points—negative DIF—are used (1, 2, 3).

Some aspects of the experiment appear to be contradictionary as the requirements for plant development and energy consumption tend to be incompatible.

The fast decrease in room temperature in the morning, which was believed to be essential to obtain a maximum growth retarding effect, is not in agreement with a desire to reduce energy consumption. Therefore the reduction of the room temperature was set to occur one hour before the start of the light period.

Apart from avoiding energy peaks in the morning and the evening, the negative DIF programme was given a very high priority on account of the morphogenetic effect. However, the negative effect of this priority on the energy consumption should be taken into consideration when evaluating the final results of the experiment.

The main principle in the mean temperature control is to take advantage of the free heat from solar radiation or from supplementary light to obtain the desired mean temperature before applying the heating system.

The experimental design of the room temperature programme was based upon:
- at least 3 hours at 22°C prior to the low temperature (14°C) period.
- at least 2 hours at 14°C after the high temperature (22°C) period.
- room temperature should not exceed 22°C during the light period.
- average room temperature of 18.6°C based upon the whole experimental period.

Computer control has pronounced advantages compared to an analogue control system due to a free choice of ramp functions when changing set points.

Environmental control in both greenhouses is based upon a DGT-Volmatic computer LCC 1240, which is a computer system available for commercial use.

The computer is provided with a programme call routine (4,7), which is a facility for applying individual control programmes for research as well as for commercial purposes.

The combinations of the specially designed control programme for this experiment would not have been so convenient if the programme control had not been installed.

The application of these facilities in combination with the standard control routines will be discussed and demonstrated.

This paper will report on the effect of the climatic control programme upon energy consumption and the variations in environment. The effect upon plant growth and development will be reported in a separate paper (14).

Materials and methods

Greenhouses and data acquisition

The experiment was carried out during the winter season February - April 1991 at the Department of Horticultural Engineering, Aarslev. 2 identical east-west orientated greenhouses clad with single glass and a ground area of 8×21.5 square metres were used.

A more detailed description of the facilities and data acquisition has been reported in previous papers and will therefore not be repeated here (1, 2, 3).

Experiment and referential treatment

Shading screens applied during the day at an outside irradiation above 300 W/m^2.

Shading screens applied during the night at an outside irradiation less than 2 W/m^2, instrument set point 200 lux.

Light period

The light period started at sunrise and ended 18 hours later.

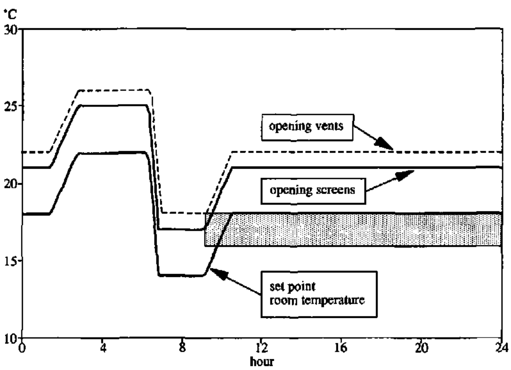

Fig. 1. The time and temperature zones of the mean temperature control. The area between upper and lower limit indicates the space of the minimum temperature set points depending on the previous mean temperature.

In Denmark the price of electricity depends on the time of day when electricity is used. In the low rated zone between 9.00 p.m. - 6.30 a.m. the price is 0.19 DKK/kWh, in the medium rated zones between 6.30 a.m. - 7.30 a.m. and 12.00 a.m. - 9.00 p.m. the price is 0.33 DKK/kWh, and in the peak rated zone between 7.30 a.m. - 12.00 a.m. the price is 0.58 DKK/kWh. Therefore care was taken in the design of the control programme to avoid the use of supplementary light in the peak rated zones. Supplementary light from 12.00 a.m. to 18 hours after daybreak whenever irradiation was less than 40 μmol/m^{2}s.

Temperature control

Low temperature period

The progress of the set points are shown schematically in Fig. 1.

3 successive ways, with falling priority were applied in order to reduce room temperature and controlled by a ramp function of 15 °C/h.

First priority :	reducing temperature of heating system.
Second priority:	opening screens. The screens opened at a room temperature 3°C higher than the present set point.
Third priority :	opening vents. The vents opened at a room temperature 4°C higher than the present set point.

Whenever the decrease of the room temperature was slower than the ramp function the method with the lower priority was set into function.

And whenever the decrease in room temperature was faster than the ramp of 15°C/h the method with the highest priority was put out of function.

By doing so the method with the lowest energy loss had highest priority and the reduction of the room temperature could be performed with highest energy preservation.

The reduction of room temperature began one hour before daybreak.

High temperature period

The high temperature period always occurred during dark period, when vents were closed and screens were drawn. It was controlled by the programme call and by a ramp function of 3°C/h.

The high temperature period began 18 hours after daybreak and ended one hour before daybreak the following day.

Mean temperature control 16°C< T <18°C
The mean room temperature was controlled by a set point calculated from an average for the past experimental period. The period in which it was allowed to correct the mean temperature ran from the end of the low temperature period one hour after daybreak until 2 hours prior to the start of the high temperature period. For 15 hours it was possible to change the set point. To obtain the temperature of 22°C in the high temperature period the lowest set point in the previous 2 hours had to be 18°C because of the ramp function of 3°C/h.

3 successive ways, with increasing priority, were applied in order to increase the mean room temperature.

First priority:	close vents for room temperatures below 22°C.
Second priority:	close screens (only during dark period)
Third priority:	increase pipe temperatures.

Referential treatment:
- zero DIF 18°/18°C day/night room temperature set points.
- ventilation at 22°C.

Results

Room temperature

When regarding the time series of the room temperature on 2 adjacent days (Fig. 2) a temperature of nearly 18°C for the referential treatment can be observed. Only during day time, when irradiation increases the room temperature above set point, a higher room temperature can be observed.

The experimental treatment showed a high night temperature for 2-3 hours. One hour prior to daybreak a fast decrease in the room temperature was observed. A low temperature of 14°C during the first 2 hours after the decrease was in accordance with the temperature control. During the afternoon the temperature was close to the max. set point of 18°C. The next day the room temperature became higher due to solar irradiation.

At 6.00 a.m. on both days it was necessary to open the screens for about 60 minutes to obtain a sufficiently fast decrease in the temperature. On the other hand it was not necessary to open the vents. During the whole experiment the screens were opened for 98 per cent of the night/day drop cases, but the vents were opened only in 13 per cent. Consequently opening the screens supplied enough cooling to comply with the temperature control strategy.

The average room temperatures for the whole experimental period was 18.8°C for the referential and 18.7°C for the experimental treatment.

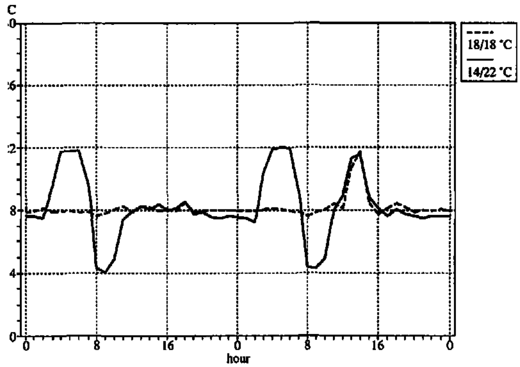

Fig. 2. The time series of room temperature in 2 greenhouses (21-22 February 1991), one with zero DIF and one with negative DIF.

Table 1. The decrease in room- and leaf temperatures from one hour before room temperature drop 22°C/16°C until one hour after. Note that decrease in leaf temperature is less than decrease in room temperature.

Temperature decrease	February-April	
°C	room per cent	leaf per cent
0 - 1		
1 - 2		
2 - 3		
3 - 4		
4 - 5	8.1	11.3
5 - 6	16.1	29.0
6 - 7	29.0	25.8
7 - 8	45.0	29.0
8 - 9	1.6	3.2
9 - 10		1.6

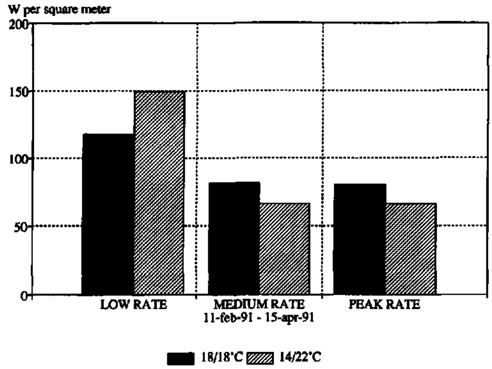

Fig. 3. The energy consumption pattern, where the consumption is divided into the three zones: low rate, medium rate and peak rate.

Difference between air and leaf temperature

When we compare the room temperature one hour before the temperature decrease (22°C to 14°C) with the room temperature one hour later it was found that the average temperature decrease was 6.7°C. The decrease in leaf temperature, however, has been low, on average 6.4°C.

Most of the decreases in room temperature were between 6 and 8°C whereas most of the decreases in leaf temperature were between 5 and 8°C. (Table 1).

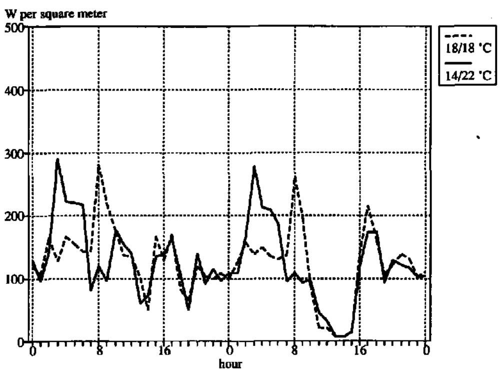

Fig. 4. The time series of energy consumption on 2 adjacent days in 2 greenhouses, one with zero DIF and one with negative DIF. The demand for a high room temperature in the dark period results in a high energy consumption. Note that energy consumption peaks are not found when negative DIF is applied (see text).

Energy consumption

The energy consumption with negative DIF was 4 per cent higher compared with the referential treatment. The higher energy consumption was caused by the need for a quick drop in room temperature and consequently a demand for opening screens and ventilators.

In the experimental treatment it was necessary to open the vents 8 times (2 hours) and to open the screens 60 times (83 hours).

The energy consumption pattern for the 2 treatments compared with the different categories of rate zones (Fig. 3) showed that in spite of the high total energy consumption for the negative DIF treatment there was a lower energy consumption in the peak rated zone as well as in the medium rated zone for this treatment. Consequently the negative DIF programme had been able to move energy consumption from the medium rated zone to the low rated zone. In other words energy consumption was moved from day hours to night hours.

Energy consumption peaks

The essential point was the pronounced energy consumption peaks with a traditional temperature control.

The energy consumption pattern (Fig. 4) for the referential treatment showed severe peaks at daybreak. For the experimental treatment this peak was avoided, but even then a decrease in energy consumption was observed. On the other hand in the first hour of the high temperature zone at night an overshoot to the higher night level was common.

In the hours of active mean temperature control the energy consumption patterns for the 2 treatments were more alike.

Table 2. Energy consumption in the two greenhouses.

	zero DIF	negative DIF	
	energy consumption W/m²	energy consumption W/m²	per cent
long-day Feb - Apr	96	100	+ 4

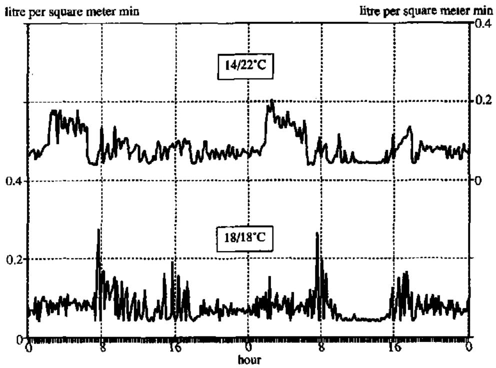

Fig. 5. Hot water flow in 2 greenhouses, one with zero DIF and one with negative DIF. Note the severe hot water consumption peaks in the greenhouse with zero DIF.

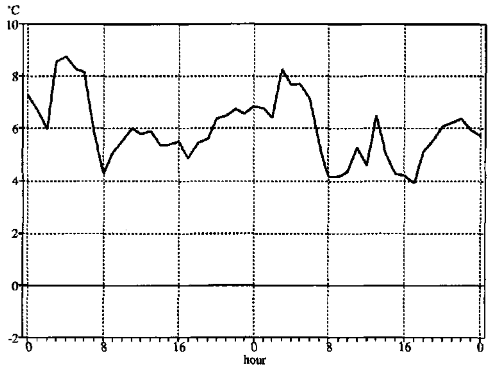

Fig. 6. Difference between leaf and dew point temperature

Hot water flow

For nurseries connected to district heating the time series of the water flow is of greater interest than energy consumption. Fig. 5 shows the water flow on 2 adjacent days in February. Severe hot water consumption peaks are seen where negative DIF is not applied (Fig. 5).

Air humidity

From the frequency table (Table 3) it can be seen that a difference between air temperature and dew point temperature less than 1°C rarely occured. Furthermore the analyses showed a generally higher difference in the hours prior to the room temperature decrease than in the hours afterwards. Low air humidity during the night, when high room temperature prevails, caused this.

Leaf temperature

Leaf temperature is the ultimate temperature to which the plants react. The difference between

Table 3. Frequency table of differences between leaf and dew point temperatures.

	Number of hours before and after room temperature drop						
	before				after		
T_l-T_d	3	2	1	0	1	2	3
°C	number of periods						
-2(-1)			1	1			
-1-0					1	1	
0-1				1			
1-2				11	19	11	3
2-3				25	23	22	14
3-4	2	15	22	12	13	11	15
4-5	29	19	17	2	3	11	19
5-6	11	10	6	5	1	3	8
6-7	7	10	9	2	1	2	1
7-8	8	4	3	2	1		
8-9	3	2	3			1	1
9-10		2		1			
10-11		1	1				1

the leaf and air temperature indicates where an expected reaction of the plants does not occur due to a discrepancy from the room temperature—which is the controlled media—and the tissue temperature—which is the reacting media—(see Table 4 and Fig. 7).

In general the leaf temperature reacts less to changes in the room temperature than to the air temperature.

The time series of the difference between leaf and dew point temperature (Fig. 6) showed that small differences and accordingly a risk for water condensation on the leaves was not very high.

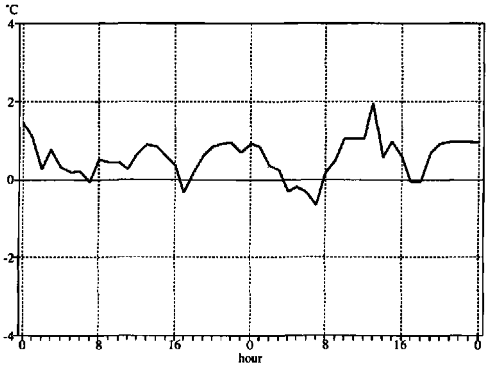

Fig. 7. Difference between leaf and room temperature

Discussion

Room temperature

To obtain a growth retarding effect of negative DIF on plant development, the decrease from night to day temperature is believed to be crucial for the result (5, 6, 8, 9, 10, 11, 12). However previous experiments show (15) that the drop in temperature does not necessarily have to be linked to the change from dark towards light period.

In this experiment therefore the temperature reduction to the low temperature period was started one hour prior to the light period.

In this way the impact of increasing radiation at sunrise on room temperature could be avoided or delayed. In a previous experiment (1, 2) where decrease in temperature coincided with sun rise this could be observed and thereby reduced the period with low temperature.

The difference in the time series of the room temperature in the 2 treatments is a result of 3 different approaches in the room temperature programme.

- The difference between zero and negative DIF programme.
- The provoked temperature reduction before start of light period with negative DIF in the experimental treatment.
- The attempt of the programme to correct mean room temperature according to target temperature in the experimental treatment.

Table 4. The number of periods of one hour, where the difference between leaf- and room temperature (T_l-T_r) has been in the indicated classes.

	Number of hours before and after room temperature drop									
	before				after					
T_l-T_r	3	2	1		1	2	3	4	5	6
°C	number of periods [per cent]									
4-5										
3-4								1		
2-3							2		2	1
1-2	2	2	2		4	5	14	15	13	12
0-1	6	4	6	7	45	46	54	48	44	41
–1-0	68	75	64	35	38	39	30	34	33	33
–2(–1)	24	17	28	54	13	10		2	8	13
–3(–2)	2		4							
–4(–3)										

Mean room temperature
The application of a mean room temperature programme has 2 purposes. Plant growth is highly dependent on the mean temperature, therefore a usable comparison of plant growth between the 2 treatments demanded identical mean temperatures. To take advantage of the irradiation heat in day-time in order to obtain a mean temperature with a minimum use of energy. It is an advantage to regain a lack in mean temperature during the night, when the greenhouse is insulated by screens. However, the very short night period under long day conditions leaves only very few hours to set mean temperature.

The unstability of the set point calculations in the previous experiment (13) was overcome to a great extent by applying a mean temperature calculated over the whole experimental period.

Energy consumption
In 1990 the morphogenetic effect of negative DIF—to reduce the application of growth retardants—lead us to try a strategy where the reduction in room temperature at sunrise was given high priority (3).

In this experiment we have moved the drop in the room temperature 1 hour prior to the start of the light period. In this way advantage could be taken of the cold atmospheric conditions and thereby reduce temperature with a minimum of energy waste e.g. by opening vents.

As a result the increase in energy was only 6 per cent compared with the experiment of 1990 (3) when the increase in energy consumption was 12 per cent.

Air humidity
The difference between dew point temperature and leaf temperature has 2 major impacts upon plant growth. High differences promote transpiration, low differences promote fungi spore germination.

For fungi spore germination periods where the difference between leaf temperature and dew point temperature is less than 1°C—the state of near condensation—for a period of more than 2 hours is considered unwanted.

Especially during decreasing room temperatures the risk of small differences between dew point temperature and leaf temperatures prevails. When room temperature reduction occured during darkness, when irradiation from lamps or daylight can increase on leaf temperature, one may expect this. However, air humidity in the greenhouse during the night is not high enough to obtain this near condensation situation in the experiments we have conducted so far (2, 3).

Conclusion

Programme call
The programme call routine (4, 7) proved its applicability. Due to this facility it was possible to combine negative DIF, mean room temperature control, supplementary light with short and long day conditions. Experiences from the previous experiments (1, 2, 3) were incorporated in this experiment and thereby some of the unwanted side effects were avoided.

The questions asked in the introduction are concluded as follows:

It is possible to avoid energy consumption peaks in morning and evening hours.

It is possible to apply the negative DIF room temperature programme, however, at the expense of an increased energy consumption of 4 per cent.

It is possible to preserve energy by reducing room temperature one hour prior to light period.

It is possible to move energy consumption to night periods by the moving average mean temperature control.

The supplementary light application dependent on low electricity tax periods has not interfered with the experimental strategy.

Acknowledgement

The financial support of these studies by grant from The Growers district heating supply Associations; North Fynen, Aasum-Langeskov and Bellinge, "Fynsvaerket" I/S, the Ministry of Energy, and the Ministry of Agriculture is gratefully acknowledged.

Literature

1. *Amsen, M. G. & Nielsen, O. F.* 1988. Simple techniques for reduction of energy consumption peaks in greenhouses. Tidsskr. Planteavl 93,27-36.
2. *Amsen, M. G. & Nielsen, O. F.* 1989. Reduction of energy consumption peaks in a greenhouse by computer control. Tidsskr. Planteavl 94, 431-440.
3. *Amsen, M. G. & Nielsen, O. F.* 1991. Negative DIF: Mean room temperature control and its effect on environment and energy consumption. Tidsskr. Planteavl 95,433-439.

4. *Borland International, Inc.* 1988. Turbo Pascal Version 5.0. Reference Manual: 654pp.
5. *Cockshull, K.; Hand, D. & Langton, A.* 1986. GCRI finds new ways to cut heating bills on ayr crops. Grower 105, 77-83.
6. *Hendriks, L. & Scharpf, H. C.* 1985. Nachtabsenkung bei Topf Chrysanthemen—lieber nicht. Gb+Gw 88, 1362-63.
7. *Ehler, N.* 1991. Interfacing crop models to standard software for greenhouse climate control. Ecological modelling 56, 245-257.
8. *Erwin, J.E.; Heins, R.D. & Karlsson, M.G.* 1987. Thermomorphogenesis in *Lillium longiflorum.* Amer.J.Bot.76(1), 47-52.
9. *Heuvelink, E.* 1988. Influence of day and night temperature on the growth of young tomato plants. Scientia Horticulturae, 38,11-22.
10. *Jacobsen, L.H.; Amsen, M.G. & Nielsen, O.F.* 1991. Negative DIF: Mean room temperature control and its effect on short day plants. Tidsskr. Planteavl 95, 441-447.
11. *Moe, R. & Heins R.D.* 1989. Control of plant morphogenesis and flowering by light quality and temperature. Acta. Hort. 272, 81-89.
12. *Mortensen, L. M. & Moe, R.* 1987. Effect of fluctuating temperature on growth and flowering of Chrysanthemum morifolium Ramat. Gartenbauwissenschaft 52(6),260-263.
13. *Nielsen, O. F. & Amsen, M. G.* 1992. Negative DIF: The effect of temperature drop prior to light period on environment and energy consumption under short day conditions in greenhouses. Tidsskr Planteavl (in print).
14. *Jacobsen, L. H.; Amsen M. G. & Nielsen O. F.* 1992. Negative DIF: The effect of temperature drop prior to the light period on plants grown under long day conditions. Tidsskr. Planteavl 96, 293-300.
15. *Amsen, M. G.; Jacobsen, L. H. & Brøndum J. J.* 1990. Negative DIF: The effect of temperature drop prior to daybreak on internode length of young tomato seedlings. Tidsskr. Planteavl 94, 503-506.

Manuscript received 15 August 1992