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The effect of temperature on leaf appearance and canopy establishment in fibre hemp (*Cannabis sativa* L.)

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Summary

The effects of temperature on the development and growth of hemp (*Cannabis sativa* L.) have never been quantified. Therefore, to establish the effect of temperature on leaf appearance and canopy establishment of fibre hemp under controlled and field conditions, plants were grown in growth chambers at 11 regimes with average temperatures between 10°C and 28°C, and three cultivars were sown in the field in March, April and May in 1990, 1991 and 1992. In the field, thermal time (base 0°C) between sowing and emergence ranged from 68°Cd to 109.5°Cd (average 88.3°Cd). Rates of leaf appearance and stem elongation increased linearly with temperature between 10°C and 28°C. The base temperature for leaf appearance was 5.7°C from the growth chamber experiments and 1°C from the field experiments. In the field, the base temperature for the relationship between light interception by the canopy and thermal time was 2.5°C, and thermal time, calculated at the appropriate base temperature, accounted for about 98% of the variance in the number of leaves and for 98.6% of the variance in the proportion of light intercepted by the canopy. Days from emergence accounted for less of the variance in both parameters than thermal time. Interception of 90% of light was attained on average at 465°Cd (base 0°C) after emergence. It is concluded that thermal time is a simple and accurate tool to describe leaf appearance and light interception in fibre hemp.

Key words: *Cannabis sativa* L., fibre hemp, temperature, thermal time, base temperature, leaf appearance, canopy establishment

Introduction

When crops are healthy and water and nutrients are not limiting, dry matter production is proportional to the amount of light intercepted by the canopy (Monteith, 1977; Meijer, Van der Werf, Mathijssen & Van den Brink, 1995). In North-west Europe, incoming radiation is greatest in May and June, but the interception of solar radiation by spring-sown

*Present address: INRA, Laboratoire d'Agronomie, 28 rue de Herrlisheim, BP 507, 68021 Colmar, France crops is never total, because the canopy is still being established. To be able to describe the light interception, growth and yield of crops, the factors affecting canopy establishment must be understood and quantified. These factors include the rates of appearance and growth of individual leaves, both of which are much influenced by temperature.

The development and growth of plants and crops can be related to temperature using thermal time, which is the accumulated temperature above a base temperature, the latter being the temperature below which the process being studied apparently stops. In field crops, the course of proportional light interception by the canopy from plant emergence to full ground cover can be described as a logistic function of thermal time (Spitters, 1990). Preliminary results (Meijer *et al.*, 1995) suggested that this approach might be effective in describing canopy establishment in hemp. However, these results need to be verified and the appropriate base temperature needs to be determined.

Base temperatures are between 0°C and 4°C for most temperate crops, and between 8°C and 15°C for crops adapted to the sub-tropics and tropics (Bierhuizen, 1973; Angus, Cunningham, Moncur & Mackenzie, 1981). As development and growth have different temperature responses (Arnold, 1959; Monteith, 1981), it is possible that the base temperatures for the two processes will be different. There is empirical evidence for such a difference in sugar beet: Milford, Pocock & Riley (1985) found that the base temperature was 1°C for leaf appearance, but was 3°C for leaf extension.

Base temperatures can be estimated from measurements of plants grown at a range of temperatures in controlled environments. The rate of development or growth is regressed on temperature, and the base temperature is estimated by extrapolating the linear relationship to its intercept with the temperature axis (Milford & Riley, 1980; Ong, 1983; Villalobos & Ritchie, 1992). Other workers have used data from field-grown crops, which were subjected to a range of temperatures as a result of different sites, years and/or sowing dates (Arnold, 1959; Angus *et al.*, 1981). These researchers estimated the base temperature as the temperature which, when used in the calculation of thermal time, minimised the variation in thermal time requirements among sites, years and sowing dates over the temperature range that is normally experienced in the phase of crop development involved (Arnold, 1959).

Very little quantitative information is currently available on the effect of temperature on the growth and development of hemp (*Cannabis sativa* L.). Haberlandt (1879) gave minimum (1–2°C), optimum (35°C) and maximum (45°C) temperatures for the germination of hemp seed. Tamm (1933) stated that hemp seed needs 96°Cd (base 0°C) for germination and emergence. No base temperatures have been reported for the growth and development of hemp. We therefore conducted experiments in controlled conditions, and in the field, to quantify the effect of temperature on the development and growth of fibre hemp.

Materials and Methods

Growth chamber experiments

Two experiments (Expt 1 in 1991, and Expt 2 in 1992) were conducted in controlled-environment chambers. Plants of fibre hemp cultivar Kompolti Hybrid TC were grown in 5 litre pots, with drainage holes, filled with a peat-based potting mixture (65% organic matter), to which 1.33 g N, 1.55 g P_2O_5 and 2.65 g K_2O fertiliser were applied per pot. Ten seeds were sown per pot, and then covered by a 1 cm layer of fine potting mixture. Seedlings were thinned to three (Expt 1) or two (Expt 2) per pot when the second pair of true leaves appeared. The pots were watered by hand from above the soil surface. Watering depended on evapotranspiration and it tended to be more frequent at higher temperatures.

The floor space of the growth chambers was 14 m^2. The light source in the chambers consisted of 18 Philips SON-T lamps and 18 Philips HPI-T lamps giving a light intensity at plant level of about 110 (Expt 1) and 90 (Expt 2) W m^{-2} (400–700 nm). The plants were grown under a 16/8 h (day/night) photoperiod and thermophase regime, and relative humidity was maintained at 70%. Each chamber contained 30 pots, arranged in a rectangle of five by six pots. Plant density was about 60 (Expt 1) or 40 (Expt 2) m^{-2}. The pots on the outer edges of the rectangle were not used for measurements.

Expt 1 had one constant temperature (19°C) and three differential day/night temperature regimes (12/6°C, 19/10°C and 26/14°C), which corresponded to daily mean temperatures of 10°C, 16°C and 22°C. Expt 2 had four constant temperatures (13°C, 19°C, 25°C and 28°C) and three differential day/night temperature regimes (12/6°C, 18/12°C and 24/18°C), theoretically corresponding to daily mean temperatures of 10°C, 16°C and 22°C. However, for the 18/12°C temperature regime the night temperature was not controlled perfectly; on several occasions it was 17°C instead of 12°C. As a result, average daily mean temperature was actually 16.5°C.

The experimental period extended from sowing to the 10-leaf stage (Expt 1) or the 12-leaf stage (Expt 2). The *n*-leaf stage is defined as the stage at which the leaves of the *n*th pair of leaves (not counting the cotyledons) are 1 cm long. In Expt 1, plant height was measured in 12 plants at the 2-, 4-, 6-, 8- and 10-leaf stage; in Expt 2, plant height was measured in 12 plants at all leaf stages from the 1- until the 12-leaf stage.

For each regime, the rate of leaf appearance (RLA) was calculated as the slope of the linear regression of the cumulative number of leaf pairs on time. Logistic equations relating plant height to time were fitted to the data for each temperature, and weighted mean rates of stem elongation (RSE) were calculated from the parameters of the equations (Milford & Riley, 1980). Temperature coefficients for RLA and RSE were calculated as the slopes of the regression of these parameters on temperature. Base temperatures of RLA and RSE were estimated by extrapolating the relationship to their intercepts with the temperature axis. Confidence intervals for base temperatures were calculated as in Sokal & Rohlf (1981).

Field experiments

The field experiments were carried out in 1990, 1991 and 1992 at Valthermond in north-east Netherlands on a peaty sand soil. The experimental set-up was a split-plot with three

Table 1. *Average air temperatures (°C) at Eelde over 10 (periods I and II) or 11 (period III) days*

		Year			
Month	Period	1990	1991	1992	1961–1990
March	III	7.3	5.9	4.7	5.3
April	I	5.8	9.1	6.7	6.0
	II	7.3	8.3	7.1	7.4
	III	10.7	5.7	9.9	8.3
May	I	16.1	7.3	9.4	10.6
	II	11.4	9.4	14.6	11.7
	III	10.8	10.4	19.7	12.4
June	I	13.4	10.4	17.5	14.1
	II	13.9	11.9	16.0	14.6
	III	16.6	14.1	17.7	15.1
July	I	13.8	20.6	17.3	15.8
Mean		11.6	10.3	12.8	11.0

replications. Sowing dates were main plots, cultivars were in sub-plots. The sub-plots were 14 m long and 3 m wide. The main plots were guarded on both sides by a 3 m-wide strip of hemp. The sowing dates were 19 March, 2 and 17 April and 1 May in 1990; 20 March, 9 and 25 April and 22 May in 1991; 25 March, 21 April and 6 May in 1992. On 29 May 1990, a −7°C ground frost damaged the crops sown on 2 and 17 April, so data from these crops were not used in the analyses. On all sowing dates in each year, except for 20 March 1991, three cultivars were sown: the French monoecious cultivar Fédrina 74 and the Hungarian dioecious cultivars Kompolti Hybrid TC and Kompolti Sárgaszárú. On 20 March 1991, only Fédrina 74 was sown; in 1992 the French monoecious cultivar Futura 77 (which is similar to Fédrina 74) was used instead of Fédrina 74. Crops were sown at 4 cm depth with a studded roller seed drill at 12.5 cm row width.

P and K fertilisers were applied somewhat in excess of recommendations for arable crops, in order to avoid shortage of P and K limiting yields. N fertiliser was applied at rates of 100 kg ha^{-1} in 1990 and 1991, and 120 kg ha^{-1} in 1992. Herbicides were not used, as weeds were generally suppressed by the crop; when necessary, weeds were removed by hand. To prevent the occurrence of *Botrytis cinerea* and *Sclerotinia sclerotiorum*, the crop was sprayed with fungicides (alternating vinclozolin at 500 g ha^{-1} and iprodione at 500 g ha^{-1}) at 14-day intervals during June, July and August.

After sowing, the density of emerged plants was counted every two or three days, and the date of 50% plant emergence was estimated by interpolation. For the crops sown on 1 May 1990, 25 April 1991 and 6 May 1992, 50% plant emergence had occurred before the first counting. For these crops, the date of 50% plant emergence was estimated from the thermal time from sowing to emergence estimated from the other sowing dates. At the 1- or 2-leaf stage, the crops were hand thinned to a density of 64 plants m^{-2}. From thinning until canopy closure, leaf stage was determined at 7- or 14-day intervals. At those times the interception of photosynthetically active radiation (PAR) by the canopy was measured with a line sensor (Technical and Physical Engineering Research Service TFDL-DLO, Wageningen, the Netherlands). About five measurements were taken above and below the canopy per plot.

Measurements of leaf stage and light interception continued until at least 95% interception of PAR was reached. The last date on which measurements were taken was 4 July in 1990, 10 July in 1991 and 23 June in 1992.

The experimental period extended from the end of March (the earliest sowing date) until the end of June or the beginning of July (the last measurements). In 1990 this period was 0.6°C warmer than normal (the 30-year average), in 1991 it was 0.7°C colder than normal and in 1992 it was 1.8°C above normal (Table 1). In each of the three years, the crops sown on the first date (March) experienced lower temperatures than the crops sown on the last date (May) (Table 1). Average air temperatures over 10 days ranged between 4.7°C and 20.6°C. Daily mean air temperatures were calculated as the average of daily minimum and maximum air temperatures measured at Eelde meteorological station 35 km from the experimental site. Daily thermal time (t′) was calculated as:

$$t' = \{(T_a - T_b); \text{ or } 0 \text{ if } (T_a < T_b)\}$$

where T_a is the daily mean air temperature and T_b is the base temperature. The base temperature for leaf appearance was estimated from the linear regression of leaf stage on thermal time from 50% plant emergence. We used an iterative procedure to calculate the base temperature that minimised the residual variance of this regression. The base temperature for canopy establishment was estimated similarly, using a logistic equation relating the proportion of incident light intercepted by the canopy to thermal time from 50% plant emergence.

Results

Growth chamber experiments

In Expt 2, the plants grown at the 24/18°C temperature regime grew poorly, for unknown reasons. Therefore, the data from this treatment were not included in the analyses. In both experiments, the rate of plant development and growth rate increased linearly with mean temperature. The results were similar at constant or differential day/night regimes. Consequently, the data from the two experiments and from constant and differential temperature regimes were pooled for the analyses.

In both experiments, leaf number increased linearly with time at all temperatures (Fig. 1). The time taken from 50% plant emergence to the 10-leaf stage ranged from 19 days at 28°C to 86 days at 10°C. The rate of leaf appearance (RLA) increased linearly with temperature between 10°C and 28°C, with a temperature coefficient of 0.023 pairs of leaves day^{-1} $°C^{-1}$ (Fig. 2). The estimated base temperature for leaf appearance was 5.7°C, with a 95%-confidence interval from 2.4°C to 8.4°C. The inverse of the slope of the regression of RLA on temperature is the thermal time required for a pair of leaves to appear. The thermal time required for the appearance of a single leaf (a phyllochron) was 21.9°Cd (base 5.7°C).

After an initial exponential phase, at all temperatures in both experiments, stem length increased approximately linearly with time up to the last measurement (Fig. 3). The weighted mean rate of stem elongation increased linearly with temperature between 10°C and 28°C (Fig. 4). The estimated base temperature for stem elongation was 2.5°C, with a 95%-confidence interval from −3.7°C to 6.7°C.

Field experiments

The number of days between sowing and emergence ranged from 7 to 16; the average was 10.9 (Table 2). Thermal time (base 0°C) between sowing and emergence ranged from

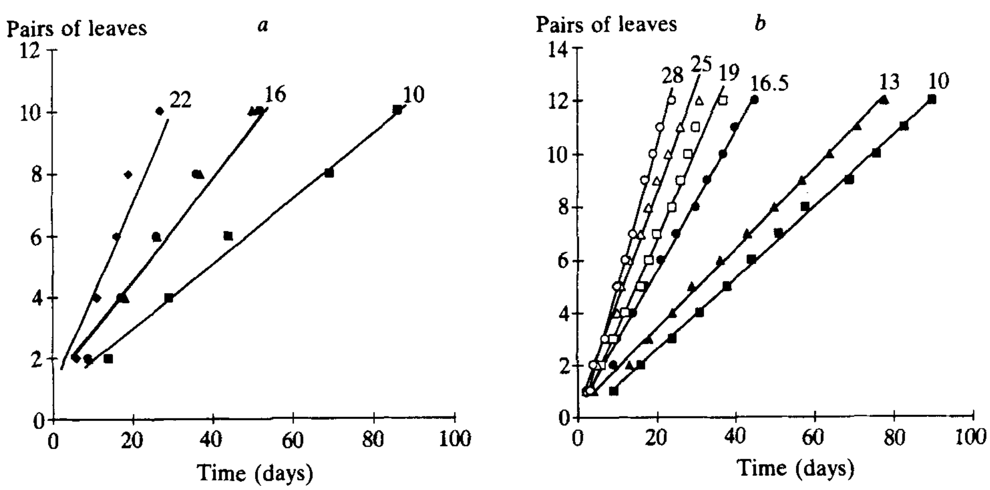

Fig. 1. Pairs of leaves versus days from emergence for hemp plants grown at different temperatures, *a)* Expt 1, *b)* Expt 2. Mean temperatures (°C) are indicated for each line.

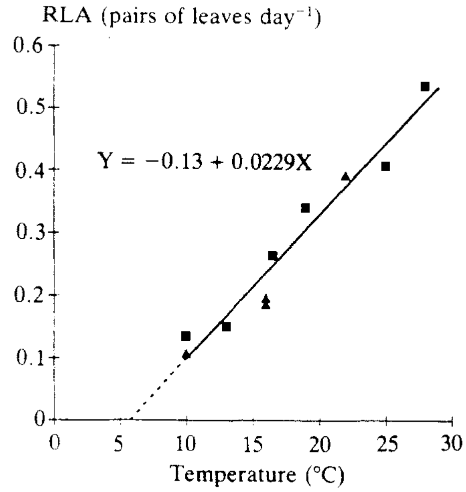

Fig. 2. Rate of leaf appearance (RLA) versus mean temperature. Triangles Expt 1, squares Expt 2; 94.1% of variance accounted for.

68°Cd to 109.5°Cd, the average was 88.3°Cd. Results did not differ significantly between the three cultivars. Coefficients of variation (CVs) were about 30% for days between sowing and emergence, and were about half as large for thermal time between sowing and emergence (Table 2). For all three cultivars, the CVs for thermal time between sowing and emergence were smallest at base temperatures 0°C and 1°C and greatest at higher base temperatures (Table 3). After emergence, leaves appeared at an average rate of 0.152 pairs of leaves day^{-1}, which corresponds to one pair every 6.6 days (Fig. 5*a*). However, rate of leaf appearance varied, e.g. at 40 days after emergence, between four and 10 pairs of leaves were present depending on sowing date, season and cultivar. Days from emergence accounted for 84.2% of the variance in leaf stage, whereas thermal time from emergence (base 1°C) accounted for 97.8% of the variance in leaf stage (Fig. 5*b*). Leaves appeared at a rate of 0.0149 pairs of leaves °Cd^{-1}. The thermal time required for the appearance of a single leaf (a phyllochron) was 33.5°Cd (base 1°C).

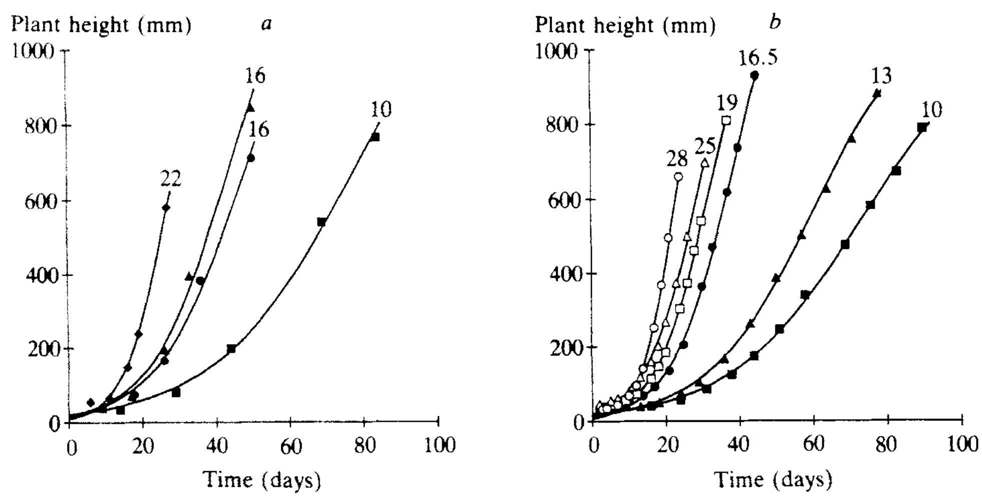

Fig. 3. Stem length versus days from emergence of hemp plants grown at different temperatures, *a*) Expt 1, *b*) Expt 2. Mean temperatures (°C) are indicated for each curve.

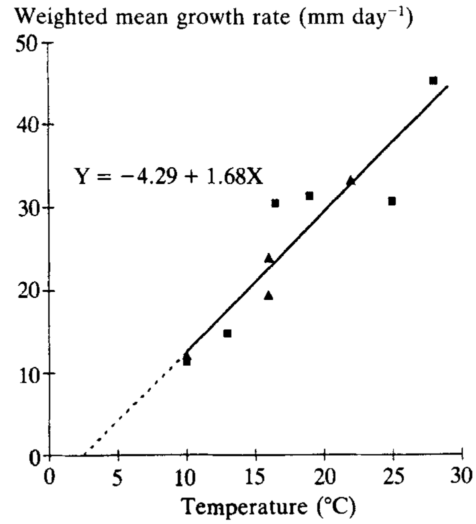

Fig. 4. Weighted mean rate of stem elongation versus mean temperature. Triangles Expt 1, squares Expt 2; 85.3% of variance accounted for.

Table 2. *Days and thermal time (base 0°C) between sowing and 50% plant emergence for fibre hemp cultivars Fédrina 74, Kompolti Hybrid TC (HTC) and Kompolti Sárgaszárú (Sár.)*

		Days to 50% emergence			°C days to 50% emergence		
Year	Sowing date	Fédrina	HTC	Sár.	Fédrina	HTC	Sár.
1990	19 March	13	12	14	97.1	87.0	109.5
1991	9 April	11	9	10	101.8	95.4	99.0
	22 May	7	7	7	68.0	68.0	68.0
1992	25 March	16	15	15	90.8	83.7	83.7
	21 April	9	9	10	88.0	88.0	96.4
Mean		11.2	10.4	11.2	89.1	84.4	91.3
Coefficient of variation		31.3	29.8	29.5	14.6	12.0	17.4

Table 3. *The effect of base temperature on thermal time (°C days) between sowing and 50% plant emergence and its coefficient of variation (CV) for three hemp cultivars*

Base temperature	Fédrina 74		Kompolti Hybrid TC		Kompolti Sárgaszárú	
	°C days	CV	°C days	CV	°C days	CV
0	89.1	14.6	84.4	12.0	91.3	17.4
1	77.9	14.4	74.0	13.1	80.1	18.2
2	66.8	15.4	63.6	16.1	68.9	20.1
3	55.9	18.3	53.5	21.0	58.0	23.1
4	45.4	24.6	43.5	28.7	47.3	28.5
5	36.1	33.2	34.7	37.8	37.8	35.5

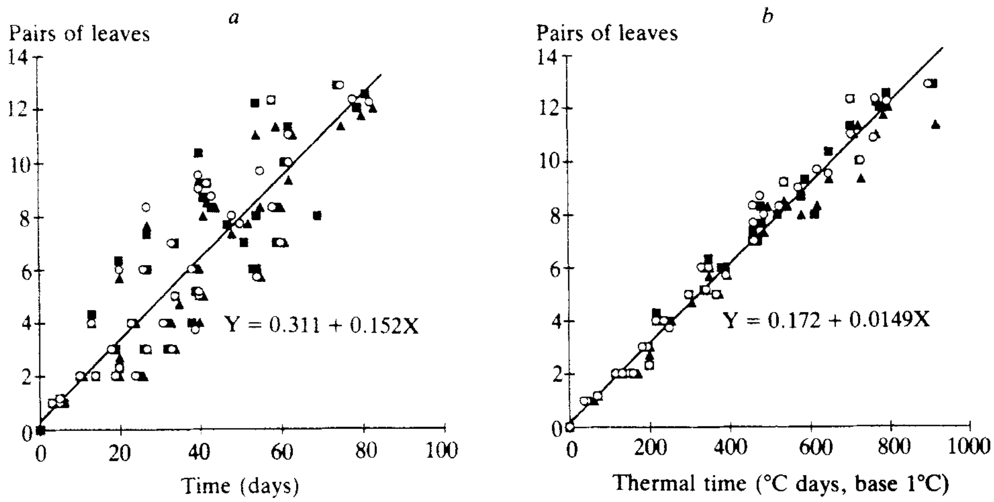

Fig. 5. Pairs of leaves of hemp plants sown in the field in 1990, 1991, and 1992. *a*) versus days from emergence, *b*) versus thermal time from emergence (base 1°C). Cultivars: Fédrina 74 (squares), Kompolti Hybrid TC (triangles) and Kompolti Sárgaszárú (circles).

The base temperature that yielded temperature sums that best accounted for the variation in leaf number was 1.40 (± 0.50)°C for Fédrina 74, 0.78 (± 0.78)°C for Kompolti Hybrid TC and 1.28 (± 0.65) for Kompolti Sárgaszárú. As the base temperatures did not differ significantly, the data for the three cultivars were combined, and a base temperature of 1°C was used, because it was an approximate average. For every cultivar, the leaf stage was regressed on thermal time using a base temperature of 1°C and, to allow comparison with the results obtained under controlled conditions, at a base temperature of 5.7°C (Table 4). At a base temperature of 1°C, regression accounted for about 98% of the variance in leaf stage, compared with 93–94% at a base temperature of 5.7°C. At both temperatures, the slope of the regression was significantly steeper for Fédrina 74 and Kompolti Sárgaszárú than for Kompolti Hybrid TC, i.e. phyllochron was larger for Kompolti Hybrid TC than for the other two cultivars (Table 4). For Kompolti Hybrid TC the phyllochrons were 35.1°Cd (base 1°C) and 22.6°Cd (base 5.7°C).

The number of days required from emergence to reach a closed canopy (> 90% intercepted PAR) varied between 27 and 69; at 20 days after emergence, the PAR intercepted by the canopy varied between 10% and 80% (Fig. 6) depending on sowing date, season

Table 4. *Linear regressions of pairs of leaves (y) on thermal time from emergence (x) with base temperatures 1°C and 5.7°C for hemp cultivars Fédrina 74, Kompolti Hybrid TC and Kompolti Sárgaszárú. Equations of the form $y = a + bx$, standard errors are shown in brackets*

Base	Cultivar	a	b	% of variance accounted for	Phyllochron (°Cd)
1°C	Fédrina 74	0.125 (0.123)	0.0153 (0.0003)	98.2	32.7
	Kompolti H. TC	0.226 (0.134)	0.0143 (0.0003)	97.8	35.1
	K. Sárgaszárú	0.176 (0.138)	0.0152 (0.0003)	97.9	32.8
5.7°C	Fédrina 74	0.752 (0.222)	0.0240 (0.0009)	93.3	20.8
	Kompolti H. TC	0.775 (0.222)	0.0222 (0.0009)	93.1	22.6
	K. Sárgaszárú	0.738 (0.219)	0.0237 (0.0009)	94.0	21.1

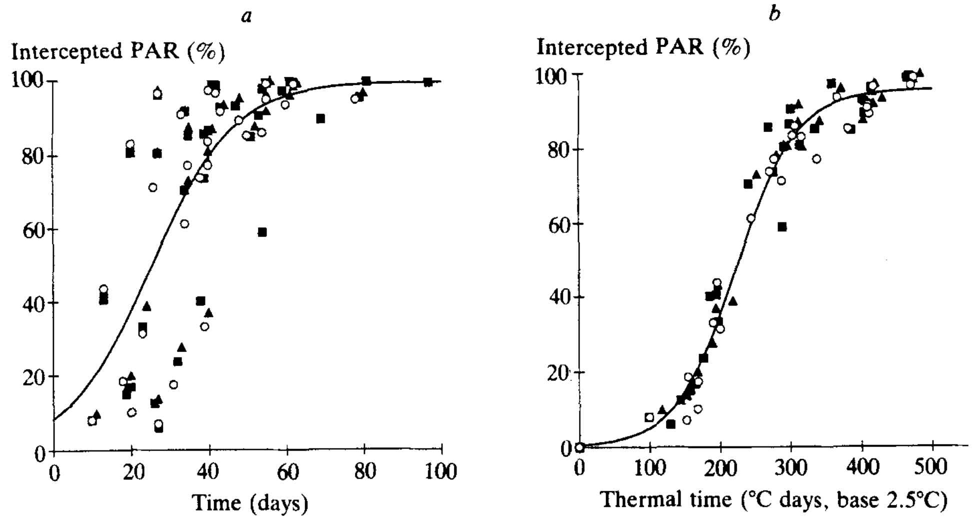

Fig. 6. Percentage of photosynthetically active radiation (PAR) intercepted by the canopy of hemp crops sown in the field in 1990, 1991, and 1992. *a*) versus days from emergence, *b*) versus thermal time (base 2.5°C). Cultivars: Fédrina 74 (squares), Kompolti Hybrid TC (triangles) and Kompolti Sárgaszárú (circles).

and cultivar. The days from emergence accounted for 53.5% of the variance in % of PAR intercepted, compared with 97.7% (base 0°C) or 98.6% (base 2.5°C) for thermal time from emergence (Table 5). The thermal time required to reach 90% interception of PAR was 465°Cd (base 0°C) or 340°Cd (base 2.5°C).

The base temperature which yielded the best fit for the regression of % PAR intercepted by the canopy on thermal time was 2.70 (± 0.47)°C for Fédrina 74, 2.23 (± 0.30)°C for Kompolti Hybrid TC and 2.57 (± 0.40) for Kompolti Sárgaszárú (Table 5). The three cultivars did not differ significantly for base temperature, or with respect to the parameters of the logistic equation relating the percentage of intercepted PAR to thermal time (Table 5).

Discussion

Base temperatures of 0°C and 1°C gave the smallest CVs for the calculation of thermal time from sowing to 50% plant emergence in the field. This agrees well with the minimum temperature of 1–2°C given by Haberlandt (1879) for the germination of hemp seed. On

Table 5. *Regression of the percentage of photosynthetically active radiation intercepted by the canopy (y) on time (x = days) or thermal time (x = °C days) from emergence for hemp cultivars Fédrina 74, Kompolti Hybrid TC and Kompolti Sárgaszárú. Equations of the form* $y = C/(1 + e^{-b(x-m)})$, *standard errors are shown in brackets*

Cultivar	x	Base temperature (°C)	C (%)	b	m (°Cd or days)	Variance accounted for (%)
All three	d		99.3 (6.1)	0.0942 (0.0204)	25.3 (2.1)	53.5
	°Cd	0	96.0 (1.0)	0.0180 (0.0009)	299 (3.6)	97.7
	°Cd	2.50	95.6 (0.8)	0.0232 (0.0009)	224 (2.2)	98.6
Fédrina 74	°Cd	2.70	95.8 (1.5)	0.0232 (0.0023)	218 (14)	98.1
Kompolti H. TC	°Cd	2.23	96.5 (1.1)	0.0230 (0.0015)	229 (9)	99.2
K. Sárgaszárú	°Cd	2.57	94.5 (1.4)	0.0234 (0.0020)	225 (12)	98.7

average, 88.3°Cd (base 0°C) were required from sowing to 50% plant emergence; this is close to the value of 96°Cd (base 0°C) given by Tamm (1933) for the germination and emergence of hemp. For germination and emergence, therefore, our field trials confirm the few results available on the effect of temperature on hemp.

A base temperature for leaf appearance of 5.7°C and a phyllochron of 21.9°Cd were estimated from the growth chamber experiments for Kompolti Hybrid TC. From the field experiments, a base temperature for leaf appearance of about 1°C and a phyllochron of 35.1°Cd were estimated. Using a 5.7°C base temperature, the field experiments yielded a 22.6°Cd phyllochron. With regard to the thermal time required for the appearance of a leaf, the results obtained in the growth chambers agree closely with those obtained in the field, as phyllochrons were similar when the same base temperature was used. However, the estimated base temperature was much lower for the field data than for the results from the growth chamber experiments. As the relationship between temperature and development rate is sigmoid rather than linear, the estimate of the base temperature will depend on the range of temperatures investigated (Arnold, 1959). Arnold (1959) and Angus *et al.* (1981) pointed out that a shift of the temperature range investigated from the linear middle section of the sigmoid curve towards the lower tail, with lead to a lower estimated base temperature. In our experiments, the plants in the field were exposed more to low temperatures (< 10°C) and less to high temperatures (> 20°C) than the plants in the growth chambers, and this probably caused the lower estimated base temperature. Clearly, the 1°C base temperature estimated from the field trials will be most appropriate for describing development during canopy establishment in the cool spring weather of the Netherlands, because it accounted for more of the variance in leaf stage than other base temperatures. The base temperature estimated from the growth chamber experiments is not realistic, because it was obtained by linear extrapolation into a temperature range in which the relationship between temperature and development rate was probably curved rather than linear.

The comparison of field results and growth chamber results is straightforward for development (leaf appearance), but for growth the two sets of data cannot be simply compared. In the field, the course of PAR interception by the canopy was measured, whereas in the growth chambers stem elongation was measured. Nevertheless, the estimated base temperatures for canopy establishment in the field and for stem elongation in the growth chambers were both 2.5°C. In the growth chamber experiments, estimates of the base temperatures for growth and development were not significantly different. In the field experiments, the base temperature for growth (canopy establishment) was significantly higher ($P < 0.05$) than the base temperature for development (leaf appearance), although the actual difference was not large (2.5 *vs* 1°C). This result agrees with findings by Milford *et al.* (1985) for sugar beet: a base temperature of 3°C for growth (leaf expansion), and of 1°C for development (leaf appearance).

In the field experiments, thermal time, calculated with the appropriate base temperature, accounted for about 98% of the variance in leaf stage and for 98.6% of the variance in the proportion of PAR intercepted by the canopy. For both leaf appearance and PAR interception, days from emergence accounted for much less of the variance than thermal time. In earlier experiments (Meijer *et al.*, 1995), 90% interception of PAR was attained at 450–500°Cd (base 0°C) after emergence, in hemp crops grown at 86–114 plants m^{-2}. In the current experiments, plant density was 64 m^{-2} and 90% interception of PAR was attained on average at 465°Cd after emergence. Thus, the results of the earlier experiments are largely confirmed here and it can be concluded that thermal time is a simple and accurate tool for describing the course of leaf appearance and light interception capacity in field-grown hemp crops.

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