Field Crops Research, 5 (1982) 129—136
Elsevier Scientific Publishing Company, Amsterdam — Printed in The Netherlands

EFFECTS OF SHORT-DURATION CHILLING TEMPERATURE EXPOSURE ON GROWTH AND DEVELOPMENT OF SORGHUM

D.J. MAJOR, W.M. HAMMAN and S.B. ROOD

Agriculture Canada Research Station, Lethbridge, Alta. T1J 4B1 (Canada)

(Accepted 8 September 1981)

ABSTRACT

Major, D.J., Hamman, W.M. and Rood, S.B., 1982. Effects of short-duration chilling temperature exposure on growth and development of sorghum. *Field Crops Res.*, 5: 129—136.

An early maturing sorghum (*Sorghum bicolor* (L.) Moench cv. Pride P130) was grown in a greenhouse with day/night temperatures of 23/18°C and transferred to a controlled environment chamber with day/night temperatures of 13/8°C for 3-, 7-, or 10-day periods starting at seedling emergence and continuing to maturity. Reductions in leaf number and plant height caused by chilling temperatures were only temporary. Chilling temperatures 28 days after emergence caused tiller number to increase from three to as many as eight per plant. While both panicle emergence and anthesis were delayed, the period between panicle emergence and anthesis was shortened after chilling treatment. Exposure to chilling temperatures did not affect kernel growth, number of kernels per panicle, yield per panicle, or anthesis of secondary tillers. Secondary, tertiary, and subsequent tillers had progressively fewer kernels, lower yields per panicle, lighter weight per kernel, and anthesed later than primary tillers. It was concluded that, although chilling temperatures of short duration might increase tiller number or reduce plant height, they would not seriously affect final yield or maturity.

INTRODUCTION

A major problem with sorghum production in southern Alberta is the poor stand establishment that results from reduced germination, emergence, and seedling growth at chilling temperatures. Sorghum requires minimum soil temperatures of 8—10°C for germination, while the optimum temperature is 24—28°C (Lenoble and Eveillard, 1972). The minimum temperature for seedling emergence is 10—12°C with a dramatic increase in percentage emergence at temperatures above 20°C (Pinthus and Rosenblum, 1961). However, Bagnall (1979) has concluded that single critical temperatures do not exist. For example, he found that night temperatures as low as 1.5°C with a day temperature of 21°C caused no chilling injury but a constant 5°C caused considerable injury to three sorghum species.

In southern Alberta, soil temperatures after early seeding are generally less than 15°C and, hence, limit germination and emergence. Consequently, early seeding to make use of the whole growing season may not necessarily be a good practice (Hart and Wells, 1965). Due to low soil temperatures, germination and seedling emergence is delayed, thus increasing the risk of seed decay and leaving the emerging seedling vunerable to soil-borne disease. Further, prolonged exposure to chilling temperatures can kill sorghum seedlings. Lenoble and Eveillard (1972) found that 15 days exposure to 8°C was lethal and McWilliam et al. (1979) found that imbibed seeds exposed to 8°C for 0—20 days had reduced mesocotyl extension after the plants were returned to 24°C. However, at locations in high latitudes such as Lethbridge, Alta., delaying seeding to allow the soil to warm increases the risk of frost before maturity.

Early seeding also influences the development of the plant directly. The period from emergence to floral initiation is lengthened as is the period from initiation to half-bloom. The time from half-bloom to maturity is reduced but the overall period from emergence to maturity is lengthened (Pauli et al., 1964). Plants grown under continuous 17/13°C day/night temperatures developed slowly and some tropical cultivars did not initiate panicles even after 200 days (Quinby, 1972).

Low temperatures lead to increases in leaf number and reductions in leaf length, internode length, and total plant height (Lenoble and Eveillard, 1972). Tiller number may also be influenced by temperature. Downes (1968) found that, while sorghum plants exposed to low temperatures before the 2-leaf stage showed no tillering response, those exposed to chilling temperatures at the 4- or 6-leaf stage produced more tillers. In field trials, early plantings also lead to increased tillering.

Extended exposure to chilling temperatures between panicle initiation and anthesis may cause male sterility (Downes and Marshall, 1971; Brooking, 1976). Intermediate chilling treatment causes partial sterility and thus reduces seed production. Only the pollen is affected as female fertility is retained. Genotypic differences in the degree of male sterility induced by chilling night temperature exist (Brooking, 1979).

Temperatures during the growing season that are suboptimal for sorghum growth and development are regularly recorded in southern Alberta. For example, the extreme minimum temperatures recorded at Lethbridge during the 5 months May to September of the 1977 growing season were −5.4, 3.2, 3.4, 2.6, and −2.2°C.

This study was carried out to assess the effects of short-duration chilling temperature exposure on growth and development of an early maturing sorghum cultivar.

MATERIALS AND METHODS

Four kernels of Pride P130 sorghum (*Sorghum bicolor* (L.) Moench), a single-cross hybrid, were planted on 24 May 1978, in each of 164 2-l black plastic pots filled with "Cornell Mix", a mixture of sand, peat, and vermiculite

(Boodley and Sheldrake, 1973). Seedlings began to emerge on 28 May 1978, and were subsequently thinned to one plant per pot. Plants were grown under natural lighting in a greenhouse in which minimum temperature was maintained (± 2°C) at 23/18°C day/night.

Exposure to chilling temperatures began on 29 May 1978 and consisted of one 3-, 7-, or 10-day exposure for each pot. There were four replications of the 23 3-day, ten 7-day, and seven 10-day treatments and the check. Exposure to the chilling temperature was accomplished by transferring the appropriate pots from the greenhouse to a controlled environment chamber (Controlled Environments Limited, Winnipeg, Man.) that was kept at 13/8°C day/night temperature regime (± 1°C) with a 15-h photoperiod. Irradiance during the 13°C light period was 175 W m^{-2} in the 400—750 nm range as measured with an ISCO Model SRS spectroradiometer (Instrument Specialties Co. Inc., Lincoln, NE) from 30 cool white fluorescent bulbs and 45 (40 W) incandescent bulbs.

Each day that one pot of a treatment was transfered from the growth cabinet to the greenhouse, the next treatment was put into the controlled environment chamber. Thus, population density in the greenhouse and chamber was constant.

Plant height, leaf number, and tiller number were recorded for each plant each week until there was no further change. Panicle emergence and anthesis of each tiller of each plant were recorded. As kernels developed, kernel dry weight of the main tiller was determined by removing ten kernels per panicle, drying for 2 days at 70°C, and weighing the kernels. This technique was similar to that described by Duncan and Hatfield (1964) for corn. After maturity, each panicle was harvested, threshed, and the kernels counted, dried, and weighed. Since linear regression did not provide an adequate fit, non-linear regression analysis was used to determine the relationship between growth variables and days using the equation:

$$y = \theta_3/[1 + e^{(\theta_1 - \theta_2 x)}] \qquad (1)$$

where y was leaf number, plant height (cm), or tiller number, x was days from emergence, and θ_1, θ_2, and θ_3 were parameters estimated by the regression analysis. The effect of the chilling temperature treatments was determined by multiple regression analysis using the general equation:

$$y = (b_0 + b_1x_1 + b_2x_1^2)\,(c_0 + c_1x_2 + c_2x_2^2 + \ldots) \qquad (2)$$

where y was the change in leaf number, or plant height, compared to the check treatment, x_1 was the length of exposure to chilling temperatures (3, 7, or 10 days), and x_2 was days after termination of exposure to the treatment.

RESULTS AND DISCUSSION

All of the variables were influenced during the chilling temperature treatments. After treatment, however, growth recovered and, consequently, by maturity there was no effect of treatment on plant height, leaf number, kernel yield, number of kernels, or weight per kernel. Exposure to chilling temperatures caused increases in tillering near 28 days after seeding emergence.

Increases in leaf numbers and heights of untreated plants were rapid after emergence (Fig. 1), averaging 0.3 leaves/day and 2.12 cm/day respectively. The exposure to chilling temperatures caused a reduction in leaf number and plant height that was proportional to the length of exposure. This finding is consistent with that of McWilliam et al. (1979) who found a reduction in mesocotyl extension rate which was proportional to the length of exposure of sorghum to 8°C. In the period following chilling treatment in this study, the effects of chilling temperatures on leaf number and plant height disappeared within 20—30 days (Fig. 1).

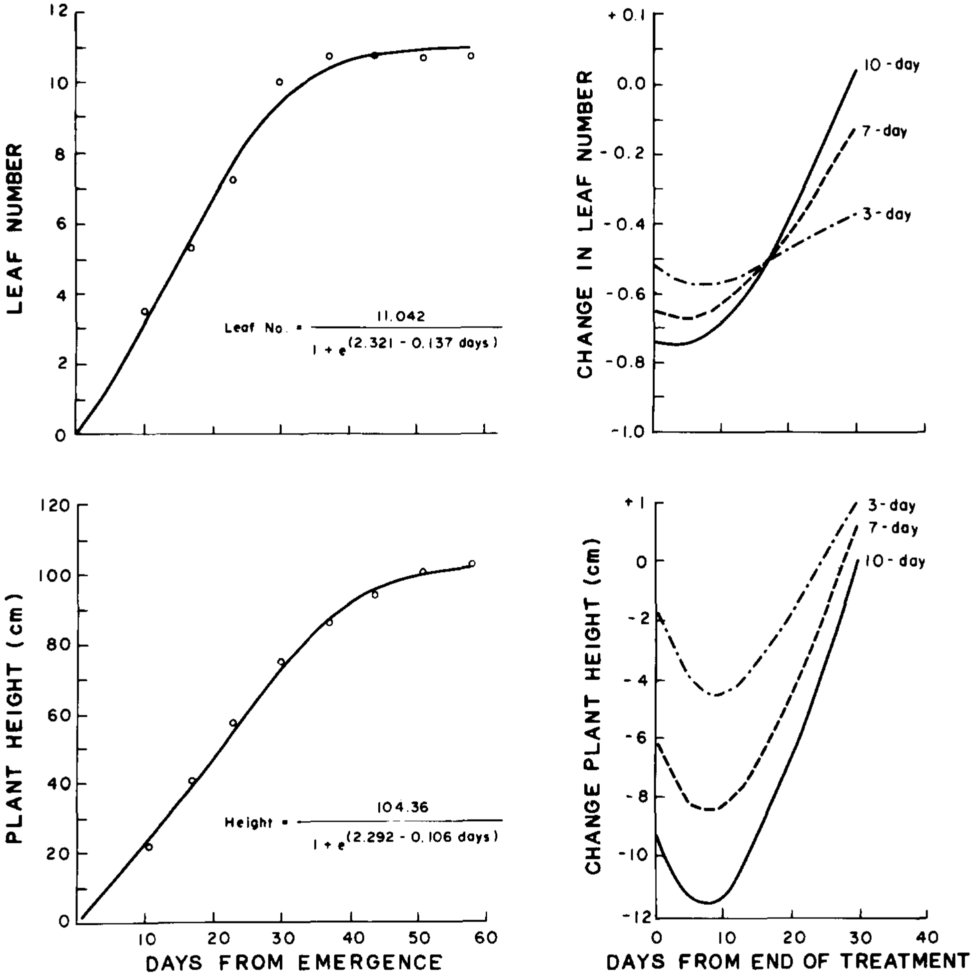

Fig. 1. Non-linear regression analyses of leaf number and plant height of sorghum vs. days from seedling emergence, and of change in leaf number and plant height vs. days after the end of the chilling treatment.

Most of the tillers appeared in a 14-day period starting about 10 days after emergence (Fig. 2). Exposure to chilling temperature during the short period when the plants were reaching maximum tiller number promoted tillering. The maximum enhancement of tillering occurred at about day 28, when all of the tillers were visible in the control treatment. Exposure to chilling temperatures caused the production of about two, five, or four additional tillers for the 3-, 7-, and 10-day exposures. This is consistent with the previous report by Downes (1968) that tillering response of sorghum to chilling treatment is dependent on the plant's age.

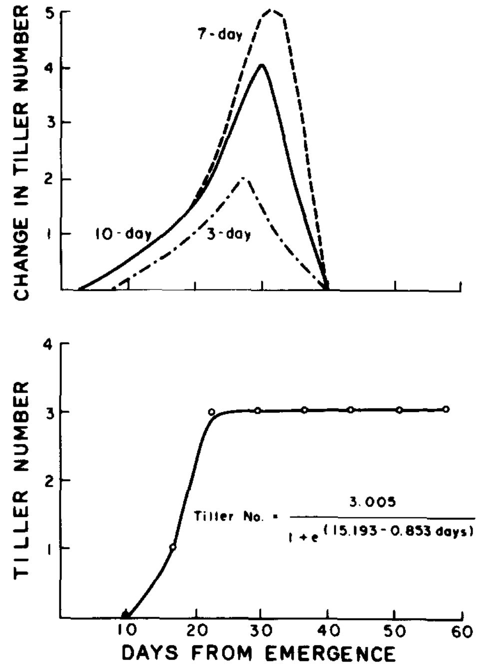

Fig. 2. Non-linear regression analysis of tiller number (excluding the primary tiller) vs. days from seedling emergence and changes in tiller number caused by the chilling temperature vs. days from seedling emergence for Pride P130 soybeans.

Panicle emergence and heading were both delayed. Orthogonal comparisons were used to determine significance of differences between treated and untreated plants (Table I). Exposure to chilling temperature for 3 days did not cause a significant delay of panicle emergence or anthesis but the 7- and 10-day exposures caused a delay of about 5 or 6 days in panicle emergence and of about 3 days in anthesis, respectively. This resulted in a shorter period from panicle emergence to anthesis and indicated that a differential influence on the timing of shoot elongation and floral development occurred. The time at which treatment was applied did not appear to affect the time to panicle emergence or anthesis suggesting that there was no interaction of temperature with stage of development.

TABLE I

Time from seedling emergence to panicle emergence and anthesis, and time from panicle emergence to anthesis of Pride P130 sorghum as influenced by 3-, 7-, or 10-day exposures to chilling temperature

Duration of exposure (days)	Time (days) to		Panicle emergence to anthesis (days)
	Panicle emergence	Anthesis	
0 (control)	38.7	47.4	8.7
3	40.7	48.2	7.8
7	43.6*	50.2*	7.5
10	44.1*	50.5*	7.2

*Different ($P < 0.05$) from control.

The technique for sampling kernel dry matter proved to be a valuable technique as a nondesctructive means of sampling kernel growth. It appeared that removing kernels had little effect on the remaining kernels. The 60 kernels removed represented only 9.9% of the total number and an effect would have resulted in a higher final kernel weight of the remaining kernels. However, θ_3, which represented the asymptote in eq. (1), was 21.91 mg and was larger than the average final kernel weight (Table II).

In spite of the 3-day delay of anthesis caused by exposure to chilling temperatures, there was no measurable effect on kernel dry matter. In addition, differences in the rate of kernel dry matter accumulation were not detected

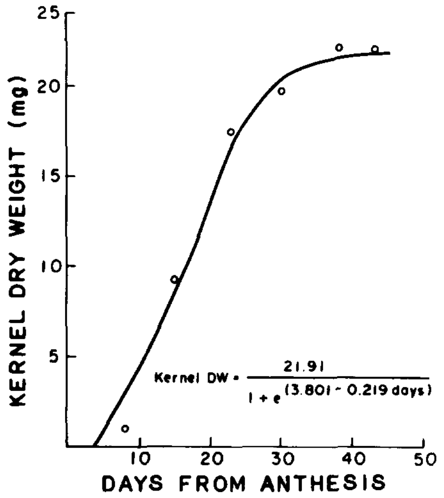

Fig. 3. Non-linear regression analysis of kernel dry weight of Pride P130 sorghum vs. days from anthesis.

TABLE II

Kernel number and yield per tiller, kernel weight, and delay of anthesis of axillary tillers compared to the primary tiller of 164 plants of Pride P130 sorghum

Tiller number	Total of tillers	Kernel number/ tiller	Kernel yield/ tiller (g)	Average weight/ kernel (mg)	Delay of anthesis (days)
1 (primary)	164	764	15.05	19.70	0
2	152	481	8.55	17.78	4.06
3	133	317	5.49	17.32	7.15
4	85	282	4.56	16.19	8.20
5	16	141	2.18	15.46	11.14

among treatments, even in plants just removed from the chilling temperature condition. Non-linear regression (eq. (1)) was used to describe the rate of kernel dry weight increase (Fig. 3).

Exposure to chilling temperatures had no effect on kernel number or kernel dry weight of any of the tillers, nor did exposure to chilling temperature delay anthesis of axillary tillers relative to anthesis of the primary tiller. Each successive tiller had progressively fewer kernels per panicle, lower yield per panicle, lighter kernels, and anthesed later (Table II). The results presented are the means of all the plants in the study. Regardless of yielding ability, the lighter kernels for each successive tiller would be a disadvantage for profusely tillered hybrids if the lighter kernels also reduced test weight.

The most surprising result of the study was the lack of a permanent reduction in growth or yield. Previous studies with C4 plants have shown that growth is significantly reduced by chilling day or night temperatures because diffusive resistance increases and photosynthesis decreases (Pasternak and Wilson, 1972; Brouwer et al., 1973). Although light and dark respiration are reduced at low temperatures, the reduced photosynthesis leads to a net reduction in growth (Ku et al., 1978).

The chilling injury resistance of the sorghum genotype studied here may relate to its selection for northerly adaptation and also that the chilling temperature used in this study was not as severe as those used in other studies. Genotypic variation for sensitivity to chilling temperature exists in sorghum (Brooking, 1979) and maturity genes, which determine time to floral initiation, also affect growth rate (Quinby, 1972). It is possible that, in the selection for northerly adaptation, Pride P130 was developed for early maturity and chilling injury resistance. Downes (1968) has suggested that a tillering response to chilling temperatures similar to that observed here for Pride P130 may result from breeding programs in which the specific adaptation to a region is defined by cold. In such a region, both chilling injury resistance and early maturity are beneficial. In addition, no sterility was observed in plants subjected to the chilling temperatures before or at flowering. Brooking (1979) found that night temperatures between 5 and 14°C caused varying degrees of sterility in a sensitive sorghum line. A line from high altitudes of Mexico, however, was fertile at all temperatures.

The results of this study indicate that exposure to chilling temperatures for short durations will temporarily reduce leaf number, plant height, and delay panicle emergence and anthesis. After return to warmer conditions, however, the sorghum hybrid Pride P130 will recover and final yield should not be reduced. Exposure to chilling temperatures at the time of early tiller growth can produce a marked increase in tiller production. The increase in tillering was the only permanent effect of the chilling temperature used in this study. The non-linear regression analyses of growth and development in this genotype will offer useful baselines for other studies of the growth of early maturing sorghums.

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