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Effects of temperature and water-regime on the emergence and yield of tomatoes[1]

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Summary

The two main problems associated with tomato production under Sudan conditions are (a) the failure of a high percentage of seedlings to emerge under nursery conditions before transplanting during the period of July till September, and (b) the failure of fruit setting in the period of April till July.
Experimental work at the Department of Horticulture at Wageningen showed that temperature and water-regime both influenced the percentage of seedling emergence. Comparing 24°, 18° and 9°C together with wet, medium and dry soil moisture conditions, the higher temperature receiving the wettest treatment showed the earliest and best emergence, followed by those at 18°. Seeds at 9°C failed to emerge even after 42 days.
A crop yield experiment showed, that high temperature, 35°C by day and 18°C by night, compared with 20°C by day and 15°C by night, in combination with the above mentioned water-regimes, all influenced tomato growth, flower structure, flower shedding and finally yield. Plants at 35/18°C, receiving the wettest treatment, had the earliest yield, soon followed by those at medium watering and finally, much later, by plants at the dry treatment. Plants at 20/15°C showed the same order in earliness but less pronounced and were all later than plants at corresponding water treatments at the higher temperature. The truss capacities were higher at the lower temperature, the water-regime effects showing the same order as for earliness. The plants at the higher temperature treatment mostly showed higher fresh weights of stems, leaves and fruits than those at the lower temperature at the same watering.

Introduction

The two main problems involved in commercial tomato production under the arid conditions of the Sudan are:
(a) A high percentage of seeds fails to germinate in the period of July till September under nursery conditions, before the seedlings are transplanted to the field. These seeds are expensive, because most of them are imported.
(b) Almost all over the country, tomato plants fail to set fruit in the period of April till July.

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Many factors may contribute to produce such effects, among them the air temperature and the water-regime of the soil. Two experiments, involving these factors, were carried out at the Department of Horticulture, Agricultural University at Wageningen, with the objectives of throwing more light on their effects.

Experimental work

Seedling emergence

Materials and methods. The experiment was carried out in the phytotron where three temperature-regimes were applied and artificial light conditions were controlled.
Twenty seven plastic pots, 5 inch in diameter, were filled with equal amounts of good soil-mixture of which the field-capacity was determined. The pots were divided into 3 groups of 9, according to temperature-regimes of 24°, 18° and 9° C. Sixteen seeds of Moneymaker variety were sown in each pot; care was taken to ensure the same spacing and sowing-depth. All pots were brought to field-capacity by addition of water while weighing. Then the 9 pots of each temperature-regime were divided into 3 groups for watering. The first group of pots, W_1 (wet), was kept at constant weight of 10% depletion from field-capacity by daily weighing and watering. In the second group, W_2, the pots were kept at 20% depletion from field-capacity weight, whereas in the third group, W_3 (dry), the pots were only brought to field-capacity weight at the beginning of the experiment and were never rewetted. The pots were then randomized in 3 blocks.

Results. The emergence of seedlings was recorded daily between 21st April, 5 days after sowing, and 7th May, when 8 plants from 24° and 18° C each were analysed. The pots at 9° C were left till 28th May and even up to then the seed failed to emerge. A comparison is therefore limited to seedlings at 24° and 18° C only.
Table 1 shows that seeds at 24° C emerged 4 and 3 days earlier than those at 18° C for W_1 and W_2–W_3 respectively. Both temperature and water-regimes influenced the emergence percentage, but the temperature effect was more pronounced, since the driest treatment at 24° C had a higher emergence percentage than any of the 3 waterings at 18° C. The differences between W_1 and W_2 in each temperature were small, but both showed a higher emergence percentage 23 days after sowing than W_3.

Table 1 Attributes taken from seedlings grown at different temperatures and water-regimes

	Temperature and water-regime					
	24° C			*18° C*		
	W_1 *(wet)*	W_2	W_3 *(dry)*	W_1 *(wet)*	W_2	W_3 *(dry)*
Emergence in days after sowing	7	8	8	11	11	11
Percentage on day of emergence	37.5	35.5	22.9	18.5	16.6	18.5
Percentage 23 days after sowing	87.5	83.3	77.1	68.8	66.6	62.5
Plant length in cm	22.1	18.6	5.1	12.0	11.1	6.0
Number of leaves > 1 cm	5.4	4.4	2.0	3.8	3.3	2.8
Fresh weight in g	3.7	2.7	0.2	1.1	0.8	0.5

The plant length also showed response to temperature and water-regimes. Again seedlings in W_1 and W_2 showed no big differences in length, but both were significantly longer than those in W_3 at both temperatures. Seedlings at 24° C were always longer than those at 18° C having the same watering, except in W_3 which might be due to the fact that at 24° C with the driest treatment the growth was checked earlier. See also figures 1 and 2. The leaf number was also affected by the temperature and water-regimes, its response being somewhat similar to that of the plant length.
On the day before harvesting all pots were brought to field capacity weight to overcome differences of last irrigation. Fresh weight of plants without roots were similarly influenced by the treatments as plant length and number of leaves. Seedlings at 24° C were much heavier than those at 18° C, comparing the same water-regime treatment, except for seedlings in W_3 treatment, which are heavier at the lower of the two temperatures, presumably because the W_3 treatment at 24° C results in a

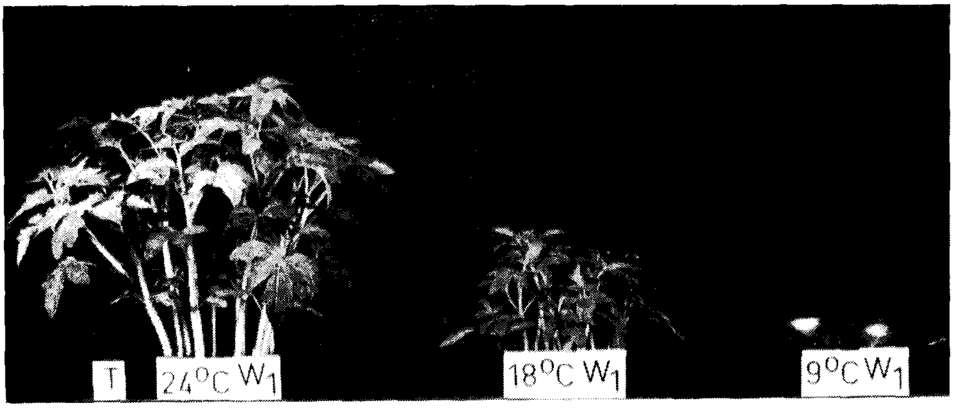

Fig. 1 Development of seedlings at constant temperatures of 24° C, 18° C or 9° C and wet (W_1) soil conditions, 24 days after sowing

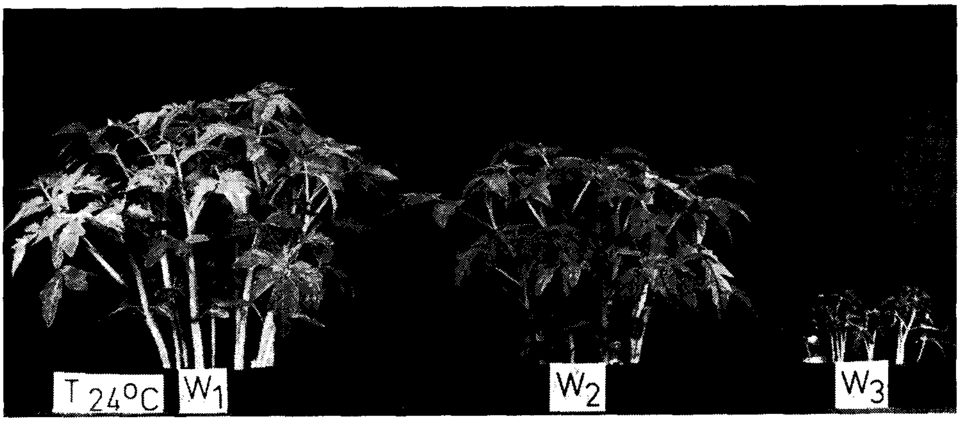

Fig. 2 Development of seedlings at 24° C and water-regimes W_1 (wet), W_2 or W_3 (dry), 24 days after sowing

much drier soil than at 18° C.

On 7th May 3 plants of each of the water-regime treatments from 24° C and 18° C were transferred to a glasshouse kept at 35° C by day and 18° C by night to detect possible after-effects on growth and development. Regular watering was practiced. These plants were analysed on 7th July as will be described in the part of the experimental work on crop yield. Differences found on 7th May did not result in clear differences found after two months of growth in the high temperature glasshouse, except for the number of leaves below the first truss. This was 11.7 after 24° C pretreatment against 9.4 after 18° C pretreatment. This is the well-known effect of temperature on number of leaves below the first truss. It may be possible that these two extra leaves after 24° C pretreatment increased the fruit set of the first truss, which was 8.3 against 7.1 after 18° C pretreatment. No after-effects of pretreatments with water-regime were found.

On 28th May also the pots of the 9° C treatments, where no seedlings emerged were transferred to a glasshouse at 35°/18° C, and later when seedlings emerged 3 plants of each water-regime pretreatment were put in large pots to continue their growth. Neither in this material differences induced by the different water-regimes before emergence could be detected on 7th July, when the experiment was ended after one month of active growth.

Crop yield

Materials and methods. Thirty pots, 8 inch in diameter, were used. The same procedure as that of the previous experiment was followed for filling the pots with soil.

Twenty seven days after sowing on 14th March seedlings were planted, one per pot. The pots were all brought to field-capacity weight and then divided into two groups of which the first one was put in a glasshouse kept at 35° C by day and 18° C by night. The second group, for comparison, was put in a glasshouse at 20° C by day and 15° C by night, but receiving only 80% incoming radiation compared to the first glasshouse. Reference will be based on the day temperatures only, hence 35° C and 20° C.

The pots in each glasshouse were again divided into 3 groups of 5 each for the following three water-regime treatments:

W_1 (wet): brought to field-capacity weight when 10% of the water present at field capacity was lost;

W_2 : brought to field-capacity weight by watering when 20% of the water present at field-capacity was lost;

W_3 (dry): brought to field-capacity weight twice: at the beginning of the experiment and when plants showed severe signs of wilting.

After having been in the temperature and water-regime treatments for 47 days, the experiment was stopped and the following measurements were taken to detect the effects of the treatments: plant lengths, leaf numbers below the first truss, capacity of trusses, fruits larger than 30 mm and larger than 5 mm, open and shed flowers, buds, rot and good fruits and stomatal openness. Also the fresh weight of the main stems, stems of side branches and their leaves, water losses from W_1 (wet) pots and evaporation from free water surface, using evaporimeters, were all recorded. In *'Results'* only part of these measurements will be considered.

Results. According to Table 2, the plants at 20° C were a little longer than those at

Table 2 Length of plants in cm grown at different temperatures and water-regimes

Water-regime	*Temperature*	
	35° C	*20° C*
W_1 (wet)	110	118
W_2	102	113
W_3 (dry)	49	59

35° C receiving corresponding watering, which may be due to light intensity differences. Plant lengths in W_1 were only slightly larger than in W_2. However, in W_3 plant growth was reduced considerably.

Truss analyses of 4 trusses of the main stem were carried out to judge total yield capacity and earliness. The theoretical means of these 4 trusses are given in the left part of Fig. 3 and discussion is partly based on this 'mean truss'.

Yield capacity, i.e. the total heights of the columns of Fig. 3 left part, was higher at 20° C than at 35° C in W_1, W_2 and W_3. At both temperatures W_1 treatment resulted in the highest capacity, W_2 being a little reduced, but W_3 being very poor. Earliness, however, indicated mainly by the black part of the columns, is larger at 35° C than at 20° C. For the water-regimes the order for earliness in W_1, W_2 and W_3 treatments was the same as for capacity, so the wetter the soil, the earlier the expected yield. W_3 failed to produce any fruits larger than 30 mm during the time of the experiment, showing the severe check to growth by this ' dry water-regime'.

Both temperature and water-regime affected the fruit numbers larger than 5 mm, but less than 30 mm. W_1 and W_2 under both temperature conditions had about equal numbers, but these were markedly higher than those in W_3.

The total number of open flowers and fruits less than 5 mm decreased with decreasing soil moisture conditions. However, those at 20° C had higher numbers than those at 35° C receiving the same watering.

The numbers of shed flowers were higher at 35° C than at 20° C, but only the 'dry' treatments had considerable amounts. The bud numbers at 35° C were less than at 20° C, showing earlier opening or fruit formation at the higher temperature. Under each temperature condition W_1 and W_2 had equal numbers, but both were exceeded by plants in W_3 showing comparatively slow development and/or growth check.

Considering the individual trusses in the right part of Fig. 3, in W_1 treatment at 35° C the first and second truss capacities are larger than those at 20° C; in the third and fourth truss the reverse is true. The reason for this could be less light in April in the 20° C glasshouse, resulting in less strong first and second truss development than at full light in the 35° C glasshouse. Later in the time at 35° C a kind of exhausting effect is found in truss development, because the first two trusses were so strongly developed; in the meantime the third and fourth trusses at 20° C had the opportunity to develop more strongly and to show the higher capacity found at 20° C compared with 35° C.

In W_2, developing more slowly differences in capacity are small, except for the fourth truss, which has a much higher capacity at 20° C than at 35° C, again showing the earlier exhausting at the high temperature.

In W_3, notwithstanding a very slow development only, the capacity of the second truss is higher at 20° C than at 35° C also.

The greater earliness at 35° C compared with 20° C in corresponding water treatments

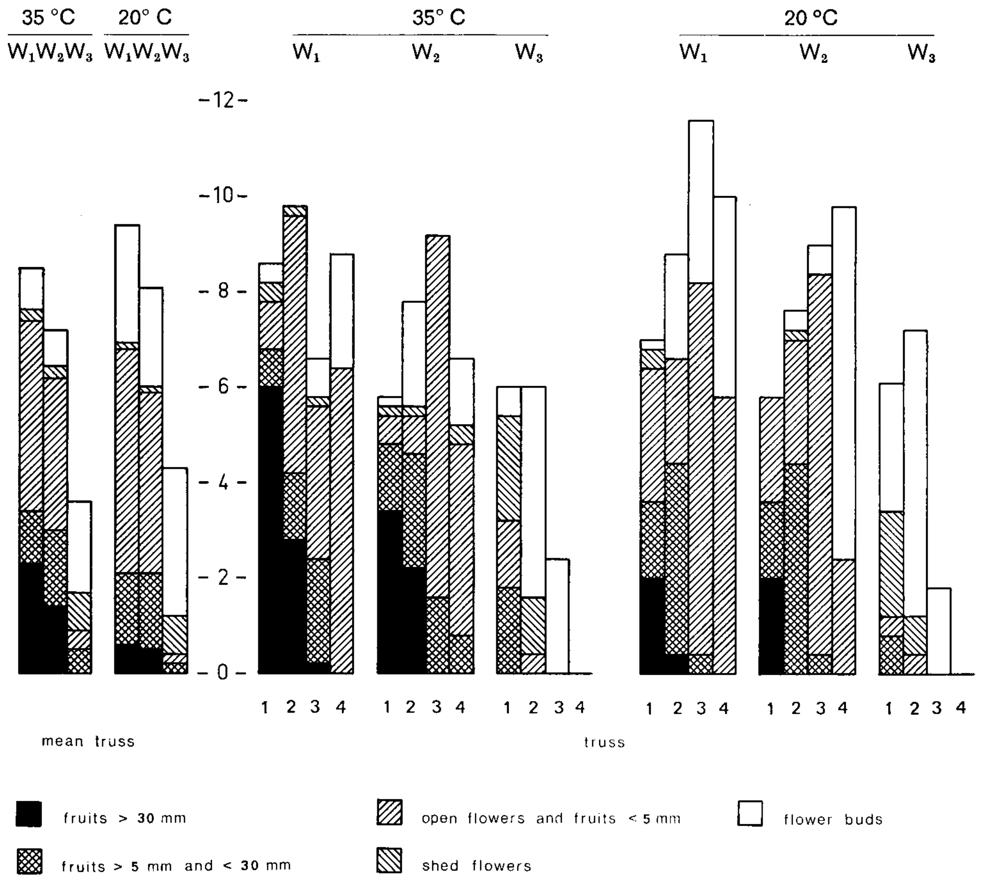

Fig. 3 Numbers of fruits, flowers and flower buds on first four trusses of plants grown at different temperatures and water-regimes. Mean of all four trusses on the left and four trusses separately on the right

is very obvious from the black parts in the columns. Both temperature and water-regime effected the flower structure. Fig. 4 shows that the corolla's of flowers receiving W_1 treatment were short and had relatively wide diameters, indicating normal characteristics, followed by those in W_2. However, those in W_3 were elongated and had comparatively smaller diameters with drying and browning tips. Such effects were more pronounced at 35°C than at 20°C. Also the styles of W_3 flowers at 35°C were much longer than the stamen tubes, indicating the unability of self pollination. A pronounced rotting at the fruit base, which is supposed to be blossom end rot, was noticed specially in W_2 treatments. About 1/5th of the total fruit number at 35°C was affected (Table 3). Such an effect may be due to irregularity in watering, which results in high water stress under high temperature conditions.

Table 4 shows that the fresh weights of the main stem and their leaves, as well as the side branches and their leaves followed a general trend. In W_1 and W_2 the plants at 35°C had heavier stems and leaves than those at 20°C. However, most

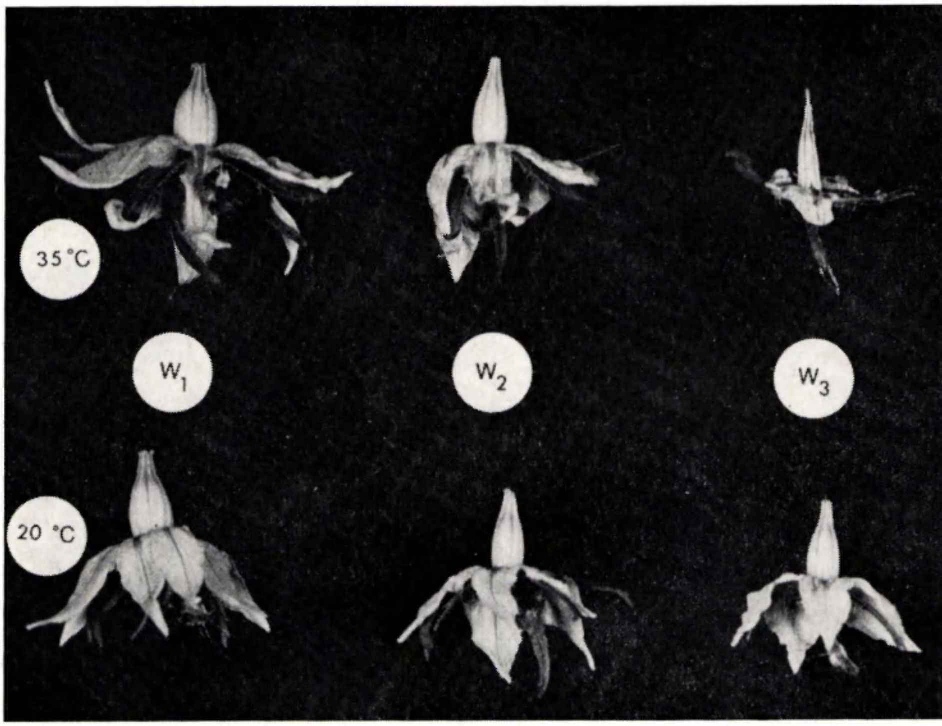

Fig. 4 Typical flowers from plants grown at 2 temperatures and 3 water-regimes

Table 3 Numbers of rot fruits compared with total fruit numbers of plants grown at different temperatures and water-regimes

	Temperature and water-regime					
	35° C			*20° C*		
	W_1 (wet)	*W_2*	*W_3 (dry)*	*W_1 (wet)*	*W_2*	*W_3 (dry)*
Fruits > 5 mm	13.4	11.8	1.8	8.4	8.4	0.8
Rot fruits	1.8	3.2	0.0	0.0	0.2	0.0

plants in W_3 at 20° C had heavier stems and leaves than those at 35° C, showing that plants at 35° C were checked earlier in their growth by the 'dry' treatment. This does not hold true for the leaves of the main stem in W_3; however, according to Fig. 5, showing a plant of each of the 6 treatments, the leaves of the main stem in W_3 are really heavier at 20° C than at 35° C.

The fresh fruit weight per truss on the main stem and on the side branches were heavier at 35° C than at 20° C (Table 4); such an effect is no doubt due to earliness and not to production capacity. Again the wetter the soil, the heavier the fruit weight. These findings are in total agreement with numbers of fruits larger than 30 mm, as shown in Fig. 3.

Table 4 Mean fresh weight of stems, leaves and fruits in g of plants grown at different temperatures and water-regimes

	Temperature and water-regime					
	35° C			20° C		
	W_1 (wet)	W_2	W_3 (dry)	W_1 (wet)	W_2	W_3 (dry)
Main stem	122.4	108.4	24.6	111.0	84.6	31.4
Stems of side branches	132.2	77.6	3.4	76.0	46.6	6.6
Leaves of main stem	182.8	173.8	59.0	126.6	104.4	53.2
Leaves of side branches	106.6	93.4	6.4	92.2	55.8	10.8
Fruits of main stem: truss 1	155.6	133.6	6.2	77.8	65.4	5.6
truss 2	50.2	49.4	0.0	21.8	20.6	0.0
truss 3	12.6	5.4	0.0	6.8	2.4	0.0
Fruits of side branches	26.2	20.4	0.0	9.4	11.1	0.0

Discussion

The seedling emergence experiment showed that both earliness and percentage of seedling emergence were influenced by temperature and water-regimes. Seeds at 24° C had an earlier and higher seedling emergence than those at 18° C. This may be due to the fact that at 24° C water was less viscous and thus more available to the seeds, and/or the temperature level was comparatively ideal for germination, whereas at 18° C the water availability and temperature were less ideal.

Failure of seedling emergence at 9° C even after 42 days, irrespective of the water-regime, showed that this temperature was below the required level for tomato seed germination, because when the pots were transferred to a glasshouse at 35° C by day and 18° C by night the seedlings appeared.

At 24° C and at 18° C it was found that the wetter the soil the higher the emergence percentage. This may mainly be due to the fact that with decreasing water content the seeds were subjected to an increasing water-stress.

Other attributes e.g. plant length, leaf number and fresh weight responses three weeks after sowing can be explained similarly.

The number of leaves below the first truss was about 2 more after growing the young plants at 24° C than after 18° C and it may be that these two leaves induced a somewhat better fruit set in the first truss of plants with 24° C pretreatment compared to those with 18° C pretreatment.

Considering the crop yield experiment data, the plant lengths were a little larger at 20° C than those at 35° C, which may be due to the light intensity differences since the glasshouse at 20° C received only 80% of incoming radiation of that at 35° C. Verkerk (1955) also found longer plants in a lower light intensity compared with a higher one.

The wetter the soil the longer the plants were, W_1 and W_2 plants showing relatively small differences, W_3 plants being strongly reduced.

As to the truss capacities and the earliness, the lower temperature treatment showed the higher truss capacity and the higher temperature the earlier fruit set and higher numbers of fruits larger than 30 mm as well as larger than 5 mm. The fruit weight showed the same temperature effect. These larger numbers of fruits of a certain size

Fig. 5 One plant out of each of the 2 temperature and 3 water-regime treatments at the end of the experiment

correspond with an earlier yield, clearly shown by Verkerk (1965). In general higher temperatures result in fewer but earlier fruits per truss compared to lower temperatures (Verkerk, 1955).

Regarding the water-regime effects on yield, the yield was continuously decreasing as the soil became drier. These findings are in line with those of Bierhuizen et al. (1959) who reported that a decrease in yield was observed in tomato when the water supply was inadequate. The effects of temperature and water-regime were also noticed in flower shedding and in modification of flower structure. Plants at 35°C had a higher number of flower shedding than those at 20°C receiving similar watering, but flower shedding was pronounced only in the dry treatments.

Flowers of plants in W_3 (dry) treatment at 35°C had styles longer than the stamen tubes and drying and browning tips, both resulting in pollination failure which may be responsible for the high percentage of flower shedding.

Lesley and Lesley (1941) and Nitsch (1962) stated that pollination does more than merely prevent flower abscission, it positively stimulates the metabolism and the growth of the fruit, whereas according to Abdalla and Verkerk (1968) the failure of fruit set by drying and browning stamens is possibly due to dry unfunctional pollen or the lack of release of pollen to the stigma.

Fruits showing blossom end rot were mainly found in the higher temperature treatment, but more in the W_2 than in the W_1 (wet) water-regime treatment.

In conclusion regular watering to maintain a wet soil is very important for earliness as well as for total yield, even more under high temperature conditions than under low ones.

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