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Scheduling of irrigation in snap bean *(Phaseolus vulgaris var. nanus)* using canopy temperature

Helyes L., Pék Z., Varga Gy. and Dimény J.

Szent István University, Department of Horticulture, Gödöllő 2103 Hungary

Summary: The present paper evaluates the result of irrigation experiments carried out on snap beans sown in spring and summer and grown with and without irrigation. The experiments were run over the course of 12 years. In the average of 12 years, the yield was 2.8t ha^{-1} for spring sown and 1.9 t ha^{-1} in summer-sown plants without irrigation. The lowest level of profitable production, the 5.5t ha^{-1} was reached twice in the case of spring sowing and only once in the case of summer sowing. Profitable yield production can be ensured only with regular irrigation and thus the yield may be increased by 4–5 times. In four of the twelve years we determined the canopy surface temperature of snap bean stands with and without irrigation. A Raynger II infrared remote thermometer determined the canopy surface temperature every day at 13.00 hours. The canopy temperature can well characterize the water supply of plant stands. This parameter may be used for describing the degree of drought and the water turnover of plant stands with different water supply. The positive values of foliage-air temperature differences (SDD) numerically express the degree of drought and the water supply of the crops. The results indicated that a 1 °C higher SDD value may cause 90–130 kg/ha yield loss.

Key words: irrigation, canopy temperature, snap bean, Phaseolus vulgaris.

Abbreviations: stress degree day (SDD), randomized complete block (RBC), available water (AW), canopy temperature (T_c), air temperature (T_a), leaf temperature (T_l) infrared (IR) water holding capacity (VK)

Introduction

The application of infrared remote thermometers was initiated by Tanner (1963). According to *Idso* et al. (1981), if soil moisture content is sufficient for the plant, the difference between plant leaf surface and air temperature is zero or negative, but if the plants suffer from water stress, this value is above zero. *Bonano & Mack* (1983) used air and plant temperature differences to schedule snap bean irrigation and to estimate yield. *Cselőtei & Helyes* (1988) established that foliage temperature data measured in the early afternoon (13:00 to 15:00) are the most adequate for the characterization of water supply. If the plants are unable to draw sufficient water from the soil necessary to meet the evaporative demand, the foliage temperature will then be higher than the air temperature. This positive temperature difference increases in relation to the lack of water and low level of soil moisture *(Helyes,* 1989).

Idso et al. (1977) and *Jackson* et al. (1977) measured canopy temperatures every day throughout a complete wheat-growing season and they defined a stress degree day (SDD) as a difference between the canopy temperature (T_c) and the air temperature (T_a).

The SDD as used by *Jackson* et al. (1981) proved insufficient to assess water stress in corn. *Gardner* et al. (1981) showed that stressed corn plants were below air temperature much of the time and suggested that corn may be more sensitive to water stress than wheat. They also suggested that canopy-air temperature differences may be soil, crop and climatic specific.

The canopy temperature of a crop can exceed the optimal temperature for some period of time even in the absence of a water deficit. Thus temperature in excess of the optimum value is not necessarily a result of water deficit and an irrigation event would not affect the canopy temperature. The amount of time that a well watered crop can exceed a given temperature threshold can be calculated from environmental date and a crop energy balance *(Upchurch* et al. 1996).

The plant water balance becomes negative as soon as the uptake of water is insufficient to meet the atmospheric requirements of transpiration *(Kramer & Boyer,* 1995; *Larcher,* 1995; *Nemeskéri,* 2001).

It has been shown that the use of infrared thermometers for remote sensing of surface canopy temperatures is a promising technique for early detection of plant stress and potentially for irrigation scheduling *(Guiliani & Flore,* 2000). Essentially a decrease in the transpiration rate is followed by a reduction in latent heat exchange between the leaf blade and the atmosphere, leading to a rise in leaf temperature which is measurable with an infrared thermometer *(Helyes,* 1990; *Hatfield,* 1990; *Jones* et al., 1997). *Gucci* (1996) showed that differences in leaf temperature between irrigated and water stressed trees were proportional to the degree of stress, while *Massai,* et al. (2000) showed that differences between stressed and irrigated trees ranges from 1–2°C in the morning to 5–6°C in the hottest part of the day.

The objectives of this paper are to:

1. Investigate irrigation scheduling of snap bean under the Hungarian ecological conditions.
2. Evaluate SDD values.
3. Determine the influence of different irrigation regimes on yield quantity.

Material and method

The water turnover and irrigation experiments with snap bean were carried out in Gödöllő (near Budapest). The experimental design used was a randomized complete block (RBC), each with 4 replications. All plots were 80 m^2. The soil in the experimental field is sandy forest soil. The subsoil water is below 5 meters; therefore it cannot influence the water turnover. The Valja variety of snap bean was used as the experimental plant in our experiments.

Water supply treatments were as follows:

1. Rain fed (unirrigated)
2. Irrigated before flowering
3. Irrigated after flowering
4. Regularly irrigated

The plots are irrigated when the soil moisture dropped below 70%. Irrigation was done by a sprinkler system, with an application rate of 40-mm m^{-2} for each irrigation event. During the 12 year study, in the case of spring-sown experiments, the sowing was done on May 16–26. The plants were harvested between July 22 and August 6. In the case of summer sown plants grown as a second crop, the earliest date of sowing was June 30, while the latest was July 17, and harvest was done between September 7 and October 1. Canopy surface temperatures of snap beans under the four treatments were measured with an infrared remote thermometer (Raynger II. type). Canopy temperatures were measured at 13.00 hours every day. Values of air temperature and global solar radiation were simultaneously recorded. Soil moisture content was measured gravimetrically at 5–10 cm increments to a depth of 100 cm twice a week.

Soil moisture content is broken down into four categories:

1. Over 75% AW (available soil water) in characteristic of the period after irrigation.
2. Between 50 and 75% AW in characteristic of the period prior irrigation.
3. Between 25 and 50% AW in characteristic of the delay irrigation.
4. Below 25% AW in characteristic of the period of drought.

At harvest the total biomass was weighted and all the parameters (number and weight of pods per plot) which characterize the quantity and quality of yield were determined.

Results

Figure 1 shows the annual yield averages of spring- and summer-sown snap beans treated with regular irrigation and without irrigation, during the 12 year period. The yield results demonstrate that snap beans did not produce yields above the profitable level (5.5 t ha^{-1}) (Hungarian Fruit and Vegetable board, 2003) under rain fed conditions – except for 2 years. In three cases of spring sowing and five cases of summer sowing yield was less than 1 t ha^{-1}.

In four years of the 12 we determined the canopy temperature from the two leafed state to the harvest. In experiments prior to these studies it was established that the values of canopy temperature are influenced by several factors, of which the absolute air temperature, the radiation and the soil moisture content are most important.

In this classification the relationship between air and canopy temperature under various water supply treatment was evaluated by linear regression analysis. The data are summarized in *Table 1* and *Figure 4*. Canopy temperatures were measured by IR remote thermometer at 13.00 hours

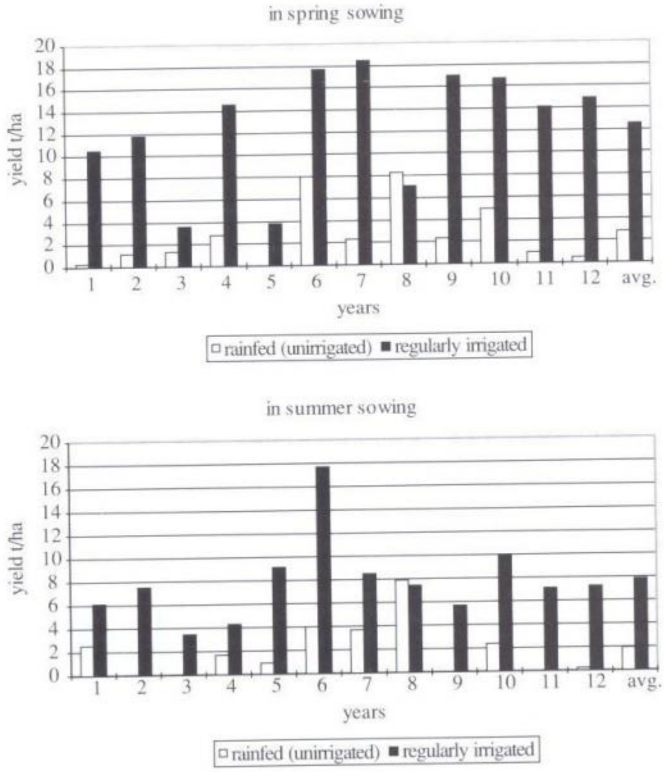


Figure 1. The effect of irrigation on the yield of Valja snap beans grown over a 12 year period
In spring-sown experiments the sowing was done on May 16–26. The plants were harvested between July 22 and August 6. In the case of summer sown plants grown as a second crop, the earliest date of sowing was June 30, while the latest was July 17, and harvest was done between September 7 and October 1

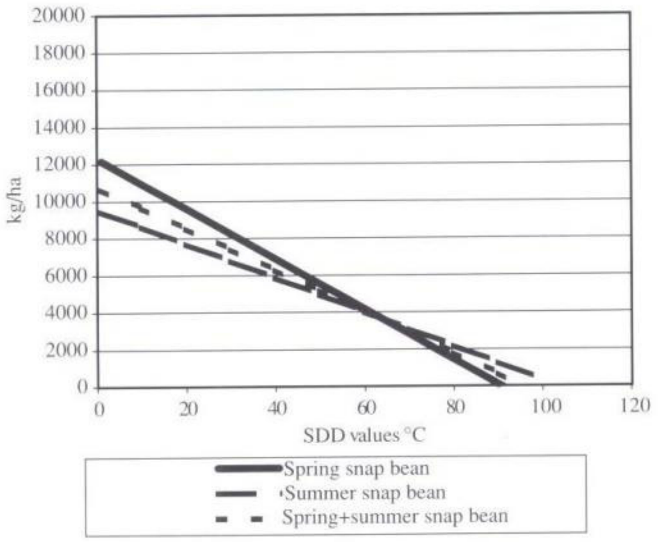


Figure 2. The relation of accumulated SDD (Stress Degree Days) values and yield in the snap bean stands during four years

every day. The high values of the correlation coefficient indicate a very close relationship between the air and canopy temperatures at all levels of soil moisture. The values of the slope of the regression line (6 values) increase with decreasing soil moisture content.

If the canopy surface temperatures are considered only for 2 soil moisture categories (above and below 50% AW) the plants grown above 50% soil moisture consistently exhibited larger values below the air temperature by an average of 2.8 °C. Thus the water supply of the snap bean stands marks the plants' demand for water, which varies daily depending on the environmental conditions.

At a soil moisture content level below 50% AW the majority of canopy temperatures exceed air temperatures by an average of 1.4 °C *(Table 1)*. This demonstrates that snap bean stands are already water limited when soil moisture content is below 50% AW.

These results verify that the changes in soil moisture content are indicated by the relationship between canopy temperature and air temperature which can be used for scheduling irrigation. The actual temperature values of snap bean stands with different water supply also reflect the degree of water supply.

In the case of water stressed plants canopy temperature is greater than air temperature. SDD is a difference between the canopy temperature (T_c) and air temperature (T_a), but only the positive values indicating the lack of water are accumulated day by day.

Table 2 shows the accumulated SDD values of snap bean stands with different water supply during four years.

The SDD values of the second and third treatments were practically the same in the case of summer sown snap bean in second year and spring sown snap bean experiments in third year. In spite of this, in the second year the third treatment gave twice as much and in third year almost three times as much yield than the second treatment.

The reason for this was that in the two treatments the period of water stress (accumulation of SDD values) occurred in different phenological phases. In the second treatment the

Table 1. The effect of soil moisture contents on the relationship between air and canopy temperature. Canopy temperatures were measured by IR remote thermometer at 13.00 hours every day

Available water (AW)	Number of days temperature °C	Average air temperature °C	Average canopy values °C	SDD	Regr. function P=0.01	R^2
75% AW	40	29.6	26.2	–	y=0.7222x+4.8	0.6952
between 50 and 75% AW	28	26.1	24.3	–	y=0.9520x–0.5	0.6430
between 25 and 50 over % AW	39	29.1	28.8	–	y=1.0360x–1.3	0.7505
below 25% AW	57	29.6	32.1	142.5	y=1.0360x–3.1	0.8052
over 50% AW	68	28.2	25.4	–	y=0.7982x+2.9	0.7139
below 50% AW	96	29.4	30.8	134.4	y=1.1479x–2.9	0.7427

Table 2. Accumulated SDD values in °C SDD (Stress Degree Days) is the difference between the canopy temperature (Tc) and air temperature (Ta), but only the positive values indicating the lack of water are accumulated day by day

Year	Spring snap bean				Summer snap bean			
	Treatments				Treatments			
	Rain fed (1)	Irrigated before flowering (2)	Irrigated after flowering (3)	Regularly irrigated (4)	Rain fed (1)	Irrigated before flowering (2)	Irrigated after flowering (3)	Regularly irrigated (4)
1st	119.6	75.8	50.8	23.3	102.2	59.5	20.8	6.7
2nd	52.8	40.9	13.0	5.8	51.0	16.5	15.3	0.0
3rd	53.8	11.9	13.4	0.0	6.5	0.0	5.2	0.0
4th	9.0	10.3	2.7	8.6	10.4	8.3	8.5	7.0

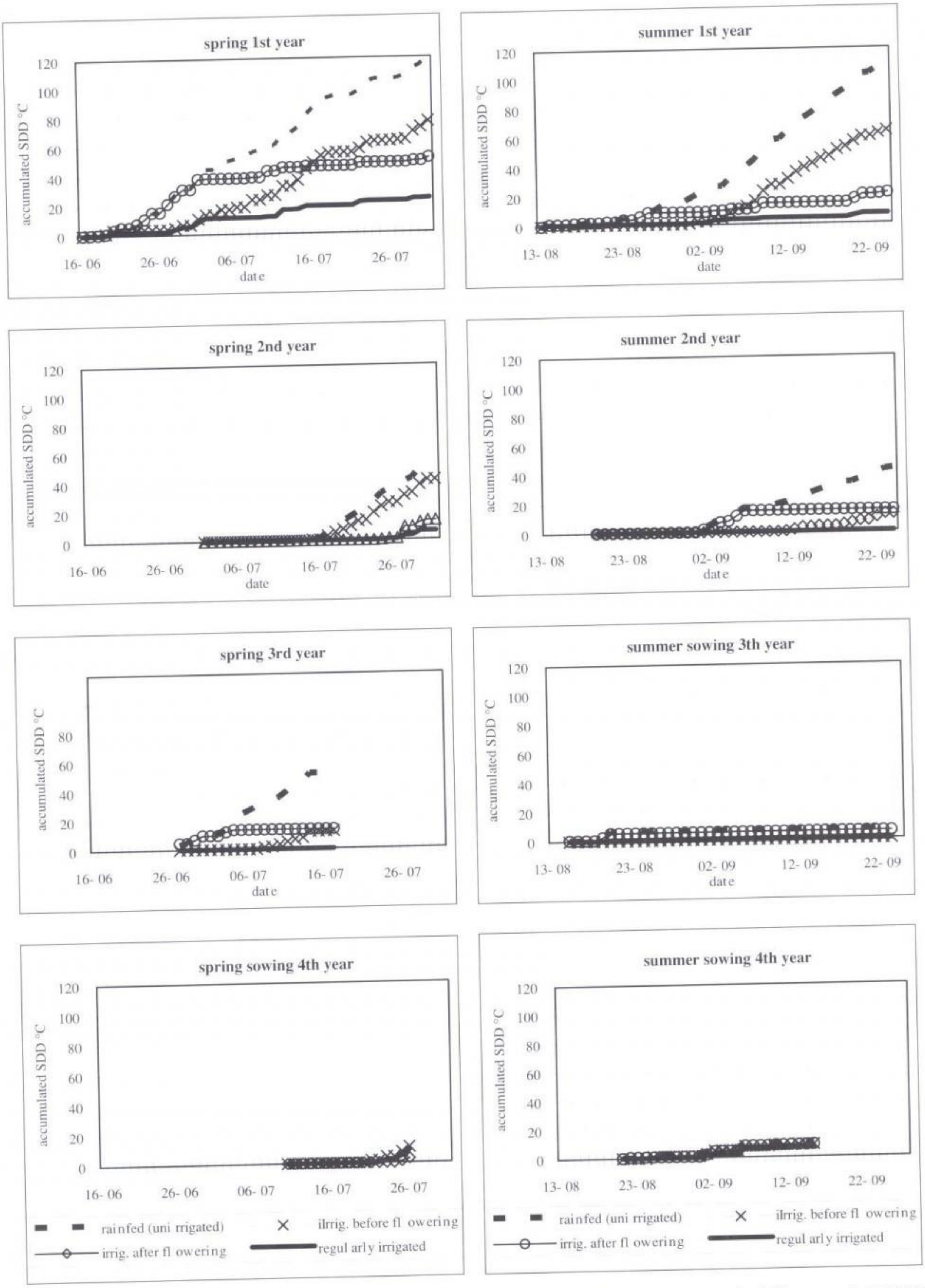
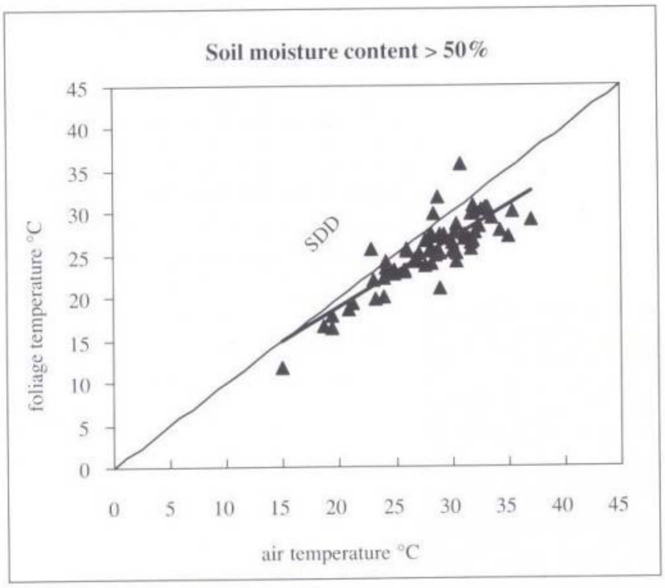


Figure 3. Accumulated SDD values of snap beanSDD (Stress Degree Days) =Tc-Ta where the positive values are accumulated. The canopy temperatures were measured at 13.00 hours every day



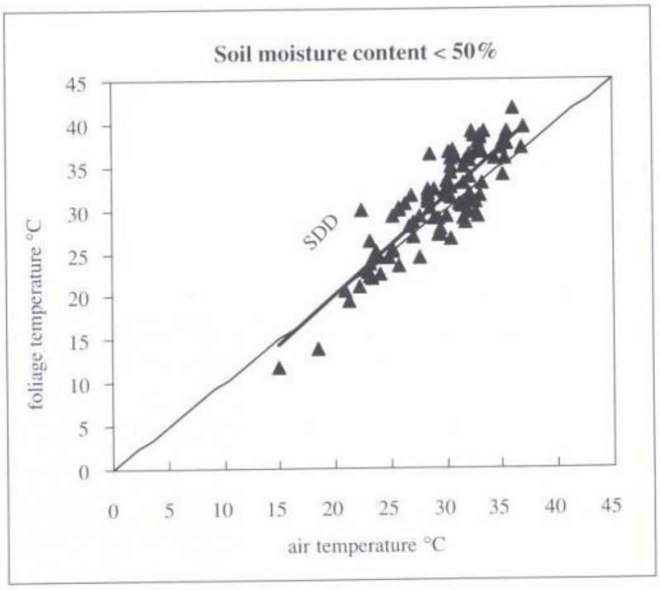


Figure 4. The effect of soil moisture contents on the relationship between air and canopy temperature Canopy temperatures were measured by IR remote thermometer at 13.00 hours every day

SDD values accumulated in the generative phase, but in the third treatment the period of water stress indicated by stronger warming of the foliage, occurred during fruiting resulting in a larger yield depression than a similar water stress in the state of vegetative development. The SDD values of our summer sown experiments in third year should have indicated high yields in that year, since according to the data, the water scarcity should not restrict the crop-development. In spite of this, the yield quantity was low except for the second treatment. The snap beans did not have sufficient soil moisture during pod forming, but the limiting factor of the yield was the low temperature. The above examples confirmed that yield is influenced by other environmental factors (nutrients, health condition, and temperature) than SDD and that SDD is only a loose predictor of crop yield.

Figure 2 shows the interrelation between the SDD values and the yield. In the spring sown experiments the interrelation is significant at P=0.01 level with r=0.7180 correlation coefficient. In the case of summer sowing, this relation is looser, but it still significant at P=0.05 level. However, the lower correlation coefficient (r=0.5467) indicates that during the four years the yield of the summer sown snap bean was determined by the SDD values to a lesser extent. Examining the spring and summer sowing together we can obtain a significant interrelation with r=0.6319 correlation coefficient at P=0.001 level.

Figure 3 shows accumulated values of SDD of canopy and air temperature for the 4 treatments and 2 sowing times over the four year period. The experiments can be divided into three groups: In the first year the natural precipitation did not result in any yield or resulted a (very) low yield of snap beans in both the spring sowing or in summer sowing. The accumulated SDD of unirrigated plants surpassed the air temperature by more than 100 °C and this high SDD indicated a considerable water stress that hampered the growth, development and pod forming of the snap bean. Thus only the regularly irrigated (4^{th} treatment) spring-sown stands and the regularly irrigated and irrigated-after-flowering summer-sown stand gave significant yields (above 5.5-t ha^{-1}). The canopy temperature data indicate that in this year snap beans could not be produced without irrigation.

The second group is represented by the experiments conducted in the spring and summer of second year, as well as in the spring in the third year. According to the three experiments, in the unirrigated (1) treatments the accumulated stress index of SDD was approximately 50 °C. In contrast to this, the canopy temperature of regularly (4) irrigated stands was not significantly higher than the air temperature. In these years the effects of irrigation on the yield quantity is significant. In the second year, the accumulated SDD values of the unirrigated and irrigated-before-flowering stand were not significantly different. Thus the water demand of the growing period requires irrigation only after flowering.

The third big group is characterized by the summer sown experiments in the third year and spring and summer sown experiment in the fourth year. The figure demonstrates that there is no difference between the treatments regarding the accumulated SDD values and this value is between 0–10 °C. In these years the growth and pod-forming of snap bean is not restricted by the water supply, therefore high yield can be achieved even without irrigation.

Conclusions

Under the Hungarian ecological conditions irrigation must be an integral part of the production technology.

Canopy surface temperature data are strongly correlated with the decrease in water availability. Canopy temperature data also indicate that soil moisture content over 50% AW can be considered optimal for snap beans, and that the water demand, which varies daily depending on environmental conditions, is met.

At soil moisture content levels between 25 and 50% AW, meeting the water demands of snap beans depends to a large extent on the environmental conditions. Soil moisture content of below 25% AW – except for some peculiar cases – fails to meet the water demand of snap bean stands.

In the case of snap beans it seems to be reasonable to irrigate if canopy temperature is higher than 29–30 °C. A higher canopy temperature than air temperature also indicates the need for irrigation.

The higher the SDD value accumulated during the flowering season, the lower is the yield result but this is a loose correlation. On the basis of the water supply/canopy temperature/yield interactions we calculated that - depending on the other production conditions – each 1 °C higher SDD value may cause 90–130 kg/ha yield loss. The canopy temperatures above 30 °C are especially harmful.

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