ELSEVIER Scientia Horticulturae 81 (1999) 409–424

SCIENTIA HORTICULTURÆ

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Scheduling strawberry irrigation based upon tensiometer measurement and a climatic water balance model

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Accepted 8 February 1999

Abstract

A field experiment was carried out over three cropping seasons with 1 year old strawberry plants (*Fragaria* x *ananassa* Duch. 'Elsanta' and 'Honeoye'), where irrigation was scheduled based upon tensiometer measurements and a climatic water balance model. Both irrigation schedules were compared to the non-irrigated one. The influence on fruiting response, the impact on soil moisture tension, mineral nitrogen content in the soil and nitrogen content in the leaves were investigated. In all the years, irrigated plants had significantly higher yields than the non-irrigated ones. The mean fruit weight was also increased by irrigation. Optimisation of irrigation was best achieved in both varieties when the climatic water balance model was used to schedule irrigation. During dry periods, soil moisture tension under non-irrigated strawberries increased to values above 300 hPa at 20 cm soil depth. In a year, with dry conditions and high evapotranspiration, maximum values above 700 hPa were reached. Differences in soil moisture were observed between the two irrigation schedules within and over the years of the experiment. The hydraulic gradients calculated from tensiometer measurements showed that in the periods with irrigation, percolation did not occur below 40 cm soil depth. Therefore, leaching of mineral nitrogen out of the rooted area of strawberries could be excluded for both irrigation schedules. The nitrogen level in dry leaf matter was not influenced by irrigation, except in one year when irrigation followed the climatic water balance model. The present study shows the potential to optimise the irrigation of strawberries using the climatic water balance model, which is less labour intensive and time consuming than tensiometer measurements. Besides the economical aspects, the results from the analysis of

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PII: S0304-4238(99)00030-8

different soil parameters indicate that scheduling irrigation based upon this model was also environmentally safe.

Keywords: Strawberries; Irrigation; Climatic water balance model; Soil moisture tension; Mineral nitrogen content in the soil

1. Introduction

Irrigation can have positive effects on strawberry growth, runner production, yield and fruit size (Naumann, 1961; Rennquist et al., 1982a, b; Dwyer et al., 1987; Savé et al., 1993). The physiological stage of June-bearing strawberries is crucial for the timing and success of irrigation in northern latitudes. The important role of water during the different growth stages of strawberries has been reported by Naumann (1964). In general, the availability of water during September and October has a strong influence on flower bud initiation and development. Water availability in April influences the development of inflorescence, and in May and June, it has an effect on fruit size. Despite this knowledge, proper timing of irrigation often remains difficult for growers without useful and objective decision-making tools. The optimal use of irrigation can be characterised as the supply of sufficient water according to plant needs in the rooting area, and at the same time, avoiding the leaching of nutrients into deeper soil levels. Several studies on the use of irrigation in strawberries have been published (Rennquist et al., 1982a,b; Al-Fahad, 1987). However, little information is given on soil moisture tension and water movement into deeper soil levels.

The aims of our experiment were to determine the effect of objectively scheduled irrigation on the yield and fruit size of strawberries and to recommend a practical method for growers to optimise irrigation. The timing of irrigation was compared using tensiometer measurements and a model derived from climatic and phenological parameters (climatic water balance model) as decision-making tools. In addition, the effects of the two irrigation schedules on soil moisture tension, mineral nitrogen content in different soil levels and nutrient supply to the plants were investigated.

2. Materials and methods

The experiment was conducted over three trial seasons on a sandy loam at Geisenheim (lat. 50°N, an annual mean rainfall of 534 mm and an annual mean temperature of 9.7°C).

A two-factor experimental design was used to compare two different irrigation regimes to a non-irrigated control treatment on two different cultivars. 'Elsanta' was always planted with freshly dug plants in the first week of August of the previous year, whereas for 'Honeoye', this was done only in 1994 and 1995. In 1996, cold stored plants of Honeoye were used and planted at the end of May. Plants were set 33 cm apart in rows with a distance of 1.0 m between each row, resulting in 26 plants per plot with a total plot area of 2.0 m $\times$ 8.6 m. After planting, overhead irrigation was used until the plants were well established.

The treatments with four replicates each were as follows:

1. Control: non-irrigated strawberry plants with natural rainfall only.
2. Irrigation according to soil moisture measured by tensiometers twice a week: irrigation was applied when soil moisture tension exceeded 200 hPa. Tensiometers were located between two plants in a row, with the ceramic tip 20 cm below the surface in the middle of the main rooting area of strawberries.
3. Irrigation according to a climatic water balance model: to start the model, the soil was saturated each year up to field capacity (100% available water, AW). For optimal plant growth, soil moisture should range between 80% and 60% AW, where AW depends on soil type. Irrigation should start when AW falls below 60% in the layer between 0 and 20 cm below the surface by subtracting the daily water balance (DW) from 100% AW on a daily basis. Irrigation should stop at 80% AW. The daily water balance is:

$$\mathrm{DW} = \mathrm{ETA} - P$$

where ETA is the actual evapotranspiration and P is the rainfall which is measured in the field. ETA is calculated as

$$\mathrm{ETA} = \mathrm{ETP} \times k_\mathrm{c}$$

where ETP is the potential evapotranspiration according to the modified Penman equation (Doorenbos and Pruitt, 1977). These data are available from the meteorological service. The crop coefficient (k_c) depends on the phenological stages of the crop. In our experiments, the following k_c values were used according to Roudeillac and Veschambre (1987):

- $k_\mathrm{c} = 0.5$ at the initiation and differentiation of flower buds in autumn,
- $k_\mathrm{c} = 0.5$ at flower development in spring,
- $k_\mathrm{c} = 0.5$–0.6 at fruit development and
- $k_\mathrm{c} = 0.6$ at harvest time.

The amount of water used for a single irrigation event is shown in Table 1. In the trial, the average irrigation quantity was set to approximately 10 mm at a time per 1 running metre plant row $\times$ 0.5 m width.

In addition, the influence of irrigation applied in autumn and spring and in spring only was investigated for Elsanta in two seasons.

Table 1
Available water at the experimental site and the calculated amount of water used for a single irrigation event

Soil layer (cm)	Available water (AW) (mm)	Calculated amount of water needed to increase AW from 60% to 80% (mm)	Amount of water used to irrigate 50 cm width per metre plant row (mm)
0–30	49.0	10.0	5.0
30–60	45.0	9.0	4.5
0–60	94.0	19.0	9.5

In the first days of September of each year, a drip irrigation system (Agro-Drip-System, emitters were spaced 30 cm apart with a flow rate of 2.7 l/h at 1.0 bar) was installed in each row of the irrigated plots. In different years, the two schedules started as listed in Table 2. Nitrogen fertilizer was applied up to an amount of 60 kg/ha in spring, according to the N_{min}-method (Scharpf, 1977), except for the year 1997, when no measurements and fertilization were done. The N_{min}-method determines the amount of nitrogen fertilizer, which represents the difference between the nitrogen requirement of a crop and the amount of mineral nitrogen measured in the rooted area. Plant protection was carried out as usual for this crop.

Fruits were picked twice a week and graded into four categories for fruit size (>25 mm, 22–25 mm, <22 mm and inferior fruits) on each picking date. Mean fruit weight was determined by weighing 50 fruits on each picking date and calculated as an average fruit weight per season.

Table 2
Total amount of water[a] used for the irrigation of the cultivars Elsanta and Honeoye in the trial seasons from 1994 to 1997 (number of irrigation events in brackets) when irrigation followed tensiometer measurements or a climatic water balance model (cwb)

Trial season	Irrigation period	Elsanta		Honeoye	
		Tensiometer	cwb	Tensiometer	cwb
1994–1995	6 September–15 October	10.4 (1)	16.9 (2)	10.4 (1)	16.9 (2)
	7 April–28 June	25.4 (2)	16.2 (1)	18.1 (1)	16.2 (1)
1995–1996	1 September–15 October	– (–)	– (–)	– (–)	– (–)
	9 April–27 June	43.1 (4)	40.0 (4)	93.7 (8)	40.0 (4)
1996–1997	4 September–15 October	12.4 (1)	10.9 (1)	40.1 (3)	10.9 (1)
	11 April–28 June	76.0 (6)	72.8 (6)	107.1 (9)	72.8 (6)

[a] Amount of water in mm needed to irrigate 50 cm width per metre plant row.

To monitor soil moisture tension in non-irrigated and irrigated plots, tensiometers were used at 20 and 40 cm depths in all trial seasons. For practical reasons, there was only one tensiometer at a given soil depth per treatment and cultivar. Soil moisture tension was measured twice a week.

Hydraulic gradients are a useful measure to describe the occurrence and direction of water movement in the soil. For Elsanta plots, they were calculated from tensiometer values according to the equation of Hartge and Horn (1991).

To determine the mineral nitrogen content in the soil of Elsanta plots, samples were taken from spring to harvest about once a month in 1996 in the layers 0–30 and 30–60 cm. Ten sub-samples per treatment and soil depth were taken between the plants in a row, mixed and homogenised. 150 g of each soil sample were extracted according to Scharpf (1977), and the content of mineral nitrogen was determined by flow injection analysis.

In each season, after some irrigation had been applied, leaf samples of the youngest fully expanded leaf from all plants in each plot were collected. Sampling dates were 30 May 1995, 24 June 1996 and 28 May 1997, respectively. Leaves were dried at 65°C, ground, and a 0.5 g sample was digested and analysed to determine nitrogen content, as described by Schaller (1993).

3. Results

3.1. Irrigation schedule

As shown in Table 2, irrigation was applied each autumn and spring, except for 1996, when rainfall in autumn exceeded evaporation (Fig. 1). For Elsanta, the

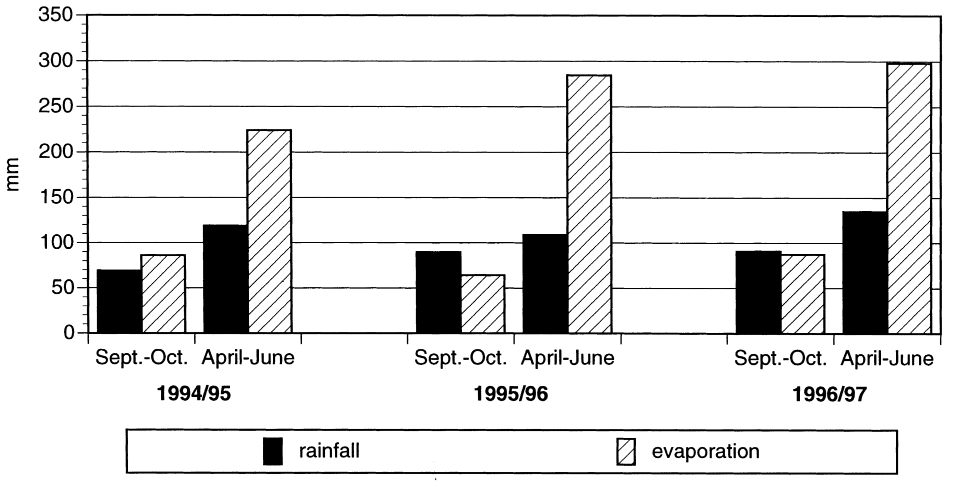

Fig. 1. Rainfall (mm) and evaporation (mm) in autumn and spring of each trial season from 1994 to 1997.

Table 3
Influence of different irrigation schedules on yield (g/plant) for Elsanta and Honeoye, 1994–1997 when irrigation followed tensiometer measurements or a climatic water balance model (cwb)

Trial season	Yield (g/plant)	Elsanta			Honeoye		
		Control (non-irrigated)	Tensiometer	cwb	Control (non-irrigated)	Tensiometer	cwb
1994–1995	total	501.0 a	508.5 a	579.7 a	262.6 a	284.0 a	316.0 a
	>25 mm	399.5 a	401.4 a	458.1 b	219.8 a	242.0 a	280.7 a
1995–1996	total	426.1 a	481.9 a	465.8 a	408.1 a	489.4 a	449.6 a
	>25 mm	340.8 a	383.6 a	376.4 a	348.1 a	412.5 a	379.7 a
1996–1997	total	426.5 a	491.7 a	500.7 a	175.4 a	225.1 ab	263.0 b
	>25 mm	359.7 a	443.8 a	460.3 a	158.2 a	211.8 ab	240.0 b

Means followed by the same letter for each variety and row do not differ significantly ($P = 0.05$).

applied amounts of water in both irrigation schedules were similar. For Honeoye, more water was applied in two of the three seasons when irrigation was based upon tensiometer measurements. In all years, due to the principles used in the climatic water balance model, both varieties received the same amount of water at the same time.

3.2. Fruiting response

Table 3 shows the influence of the two irrigation schedules on total yield and yield of fruits >25 mm in size. Frost reduced yield in 1997 by destroying many of the primary and secondary flowers (19.4% and 40.2% damaged flowers for Elsanta and Honeoye, respectively). In each cropping season, irrigated plants out-yielded non-irrigated plants, irrespective of the schedule used. This effect was also seen for the yield of fruits in the category >25 mm, which is of great economic importance to growers. In all cropping seasons, the mean seasonal fruit weight was increased by irrigation. It ranged for non-irrigated strawberries from 15.7 g (Honeoye) to 17.4 g (Elsanta) and for irrigated plants, from 17.4 to 18.5 g, respectively. The different irrigation treatments had no negative effect on *Botrytis* infection of the fruits.

In the first year, both cultivars showed a tendency for higher yields and more fruits >25 mm in size on plots irrigated according to the climatic water balance model. In contrast, in the second year, this tendency was shown by tensiometer irrigated plants. In the third year, the difference in total yield among the two irrigation schedules was smaller for Elsanta compared to Honeoye. For this cultivar, the best result was obtained with the climatic water balance model despite the fact that these plants received less water as compared to tensiometer-

Table 4
Total yield (g/plant) of Elsanta as influenced by two irrigation schedules applied in autumn and spring or in spring only when irrigation followed tensiometer measurements or a climatic water balance model (cwb)

Trial season	Non-irrigated	Autumn and spring		Spring	
		Tensiometer	cwb	Tensiometer	cwb
1994–1995	500.1 ab	469.8 a	606.0 b	547.2 ab	553.4 ab
1996–1997	426.5 a	505.6 a	544.3 a	477.8 a	457.2 a

Means followed by the same letter in each row do not differ significantly ($P = 0.05$).

based irrigation (Table 2). In conclusion, over all three seasons there is no general preference for one of the two schedules with regard to influence on yield.

For Elsanta, a comparison between autumn and spring irrigation and spring irrigation only indicated an enhanced total yield in autumn and spring irrigation (Table 4). This trend was consistent for both schedules over 2 years.

3.3. Soil moisture tension

For Elsanta, there were no remarkable differences between the levels of soil moisture tension in the trial seasons 1994–1995 and 1995–1996. Therefore, only data from the first trial season is shown and compared with the results of the 1996–1997 season. In autumn 1994, soil moisture tension at 20 cm depth was similar for non-irrigated and irrigated plots until 14 October (Fig. 2) when irrigation for both schedules reduced soil moisture tension. In spring 1995, under dry conditions, soil moisture tension in the upper layer of the non-irrigated plot increased to values around 600 hPa. In irrigated plots, the supply of water at the beginning of May reduced soil moisture tension below 250 hPa. At 40 cm soil depth, no noticeable differences between the three treatments were measured.

Soil moisture tension in the season 1996–1997, in general, reached higher values in non-irrigated plots than in irrigated plots (Fig. 3). Under non-irrigated strawberries, as there was little precipitation in September 1996, soil moisture tension at 20 cm depth and 40 cm depth reached values up to a maximum of 330 and 240 hPa, respectively. For irrigated strawberries, soil moisture tension varied below 100 hPa. In spring 1997, low rainfall and high evapotranspiration led to a constant decrease in the soil moisture tension of non-irrigated plots until the middle of June. Under such conditions, soil moisture tension reached values above 700 hPa, even at 40 cm depth. When irrigation was scheduled according to tensiometer measurements, the soil moisture tension in the upper layer varied around the defined threshold of 200 hPa. In contrast, when irrigated according to the calculated climatic water balance model, soil moisture tension varied between 300 and 730 hPa.

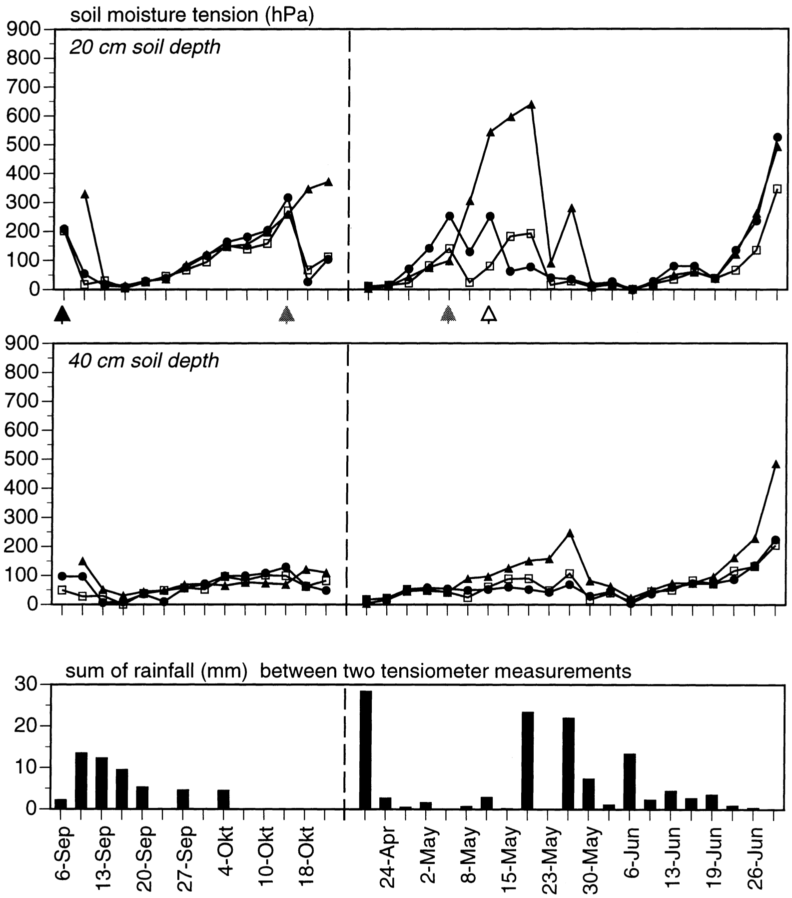

Fig. 2. Soil moisture tension (hPa) at 20 and 40 cm soil depth under Elsanta in 1994–1995 for irrigated and non-irrigated plots and the sum of rainfall (mm) between two tensiometer measurements. —▲—: non-irrigated; —●—: tensiometer-based irrigation; and —□—: irrigation based on the climatic water balance model (cwb). Irrigation events are indicated by arrows: ▲: cwb; △: tensiometer; and ▲: both schedules.

For Honeoye, the results in 1994 and 1995 were comparable to Elsanta, but not in spring 1996 and the trial season 1996–1997 (Fig. 4). Honeoye plants originating from cold-stored plants set in May showed stronger growth in autumn 1996 than Elsanta plants, which were set as rooted runners in August. Due to this difference, soil moisture tension for Honeoye plants was higher as compared to Elsanta (Fig. 3). This shows a higher water demand for these well developed plants. In autumn, with tensiometer-based irrigation, soil moisture tension under Honeoye could be kept in the region of 200 hPa with three applications of water as compared to only one application for Elsanta. In spring 1997, again, tensiometer-irrigated Honeoye required more water (nine applica-

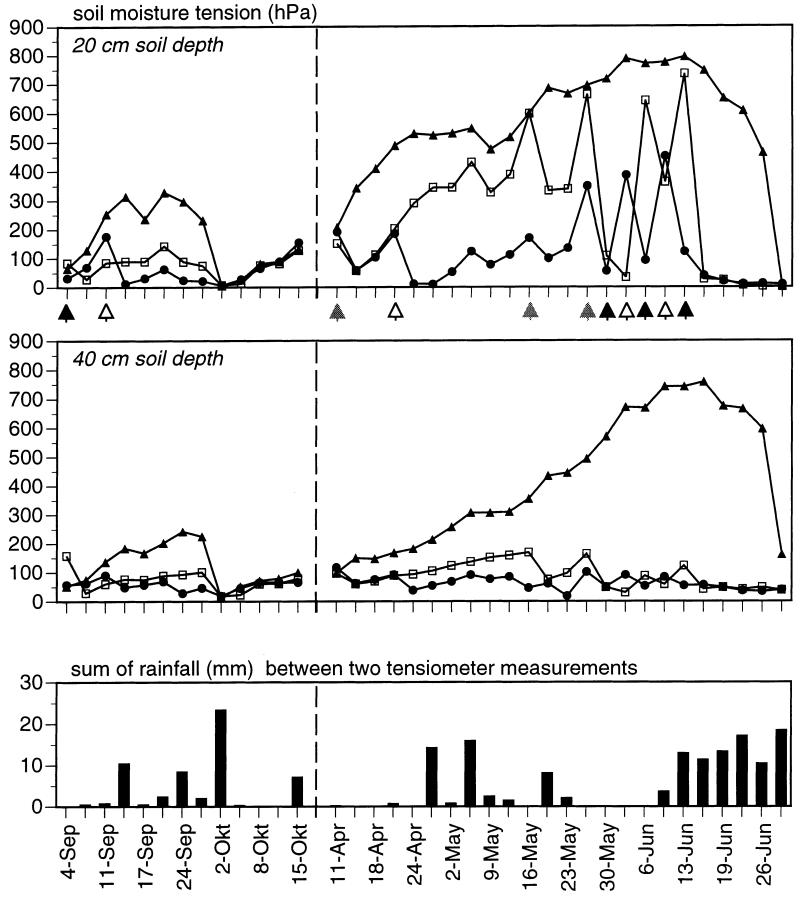

Fig. 3. Soil moisture tension (hPa) at 20 and 40 cm depth under Elsanta in 1996–1997 for irrigated and non-irrigated plots and the sum of rainfall (mm) between two tensiometer measurements. —▲—: non-irrigated; —●—: tensiometer-based irrigation; and —□—: irrigation based on the climatic water balance model (cwb). Irrigation events are indicated by arrows: ▲: cwb; △: tensiometer; and ▲: both schedules.

tions) than Elsanta (six applications) to maintain soil moisture tension at around 200 hPa. Despite irrigation, soil moisture tension reached 600 hPa during dry periods with high evapotranspiration.

3.4. Mineral nitrogen content

Fig. 5 shows the mineral nitrogen content of the soil at 0–60 cm depth in spring 1996. In 1996, N-fertilization of 30 kg/ha and mineralisation of nitrogen raised the mineral nitrogen content in non-irrigated plots from 42 to 118 kg/ha from

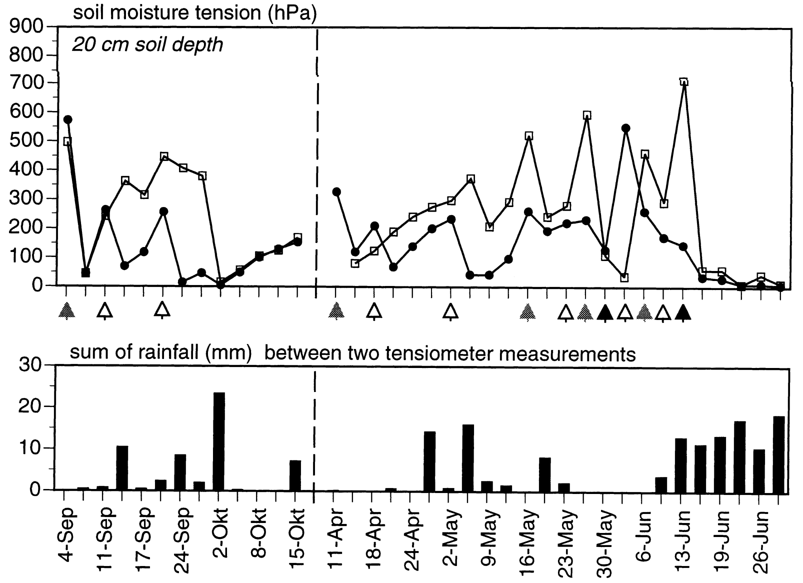

Fig. 4. Soil moisture tension (hPa) at 20 cm depth under Honeoye strawberries in 1996–1997 for irrigated and non-irrigated plots and the sum of rainfall (mm) between two tensiometer measurements. —▲—: non-irrigated; —●—: tensiometer-based irrigation; and —□—: irrigation based on the climatic water balance model (cwb). Irrigation events are indicated by arrows: ▲: cwb; △: tensiometer; and ▲: both schedules.

April to May. With irrigation, there was an increase up to 76 kg/ha in plots with tensiometer-based irrigation, and up to 104 kg/ha in plots with irrigation based upon the climatic water balance model. In the course of the trials, the reduction of mineral nitrogen in irrigated plots was stronger than under non-irrigated strawberries. Finally, in July, mineral nitrogen level decreased to an amount of 64 kg/ha in non-irrigated plots and 31 and 35 kg/ha in the irrigated plots. There was no accumulation of mineral nitrogen in the soil layer from 30 to 60 cm depth at any time. The highest value was always measured in the soil layer from 0 to 30 cm depth. Between the different sampling dates, 32.6, 54.2 and 15.5 mm of rain, respectively, occurred.

3.5. Hydraulic gradients

It is not clear whether the reduction of mineral nitrogen content in the soil is the result of nitrogen uptake by the plants or of mineral nitrogen transport into deeper soil levels and finally leaching into the ground water. Therefore, the hydraulic gradients were calculated, based on tensiometer values. At the trial site, denitrification and nitrogen immobilisation were considered to be negligible and, therefore, unlikely to be reasons for mineral nitrogen reduction. Fig. 6 shows the

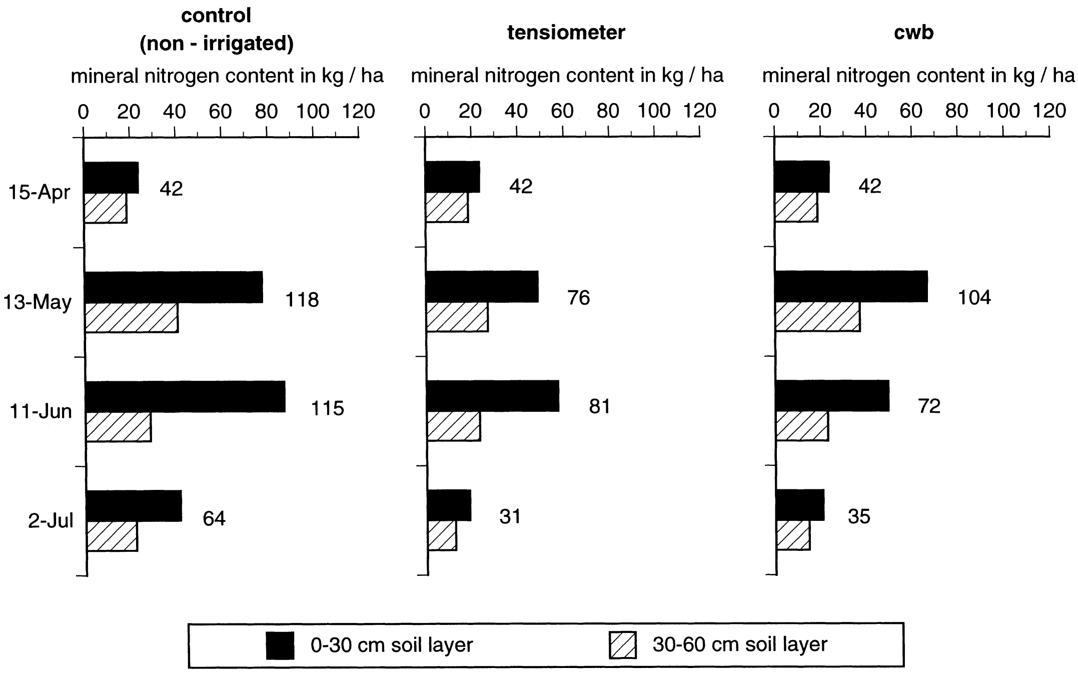

Fig. 5. Mineral nitrogen content in the soil layers at 0–30 and 30–60 cm depths as influenced by different irrigation systems in Elsanta plots in 1996. Irrigation followed tensiometer measurements or a climatic water balance model (cwb).

hydraulic gradients of the soil layer between 20 and 40 cm depth in Elsanta plots. Values less than 0 indicate an upward directed water movement, whereas values greater than 0 indicate a movement in the downward direction. A calculated hydraulic gradient of zero describes a balance where no percolation or capillary rise occurs. In all trial seasons, the hydraulic gradients tended to be negative in our study. This general trend existed for all treatments even in irrigated plots with additional water. Under the dry conditions with high evapotranspiration in spring 1997, the upward directed water movement was more pronounced under non-irrigated strawberries and plots irrigated according to the climatic water balance model.

3.6. Nitrogen content in dry leaf matter

Table 5 shows the nitrogen content in dry leaf matter for samples from the different treatments over all trial seasons. Nitrogen content in the leaves was high in the first, medium in the second, and low in the third year. In 1995, nitrogen level was significantly lower in samples from plots irrigated following the climatic water balance model. In the following 2 years, nitrogen content was not affected by irrigation.

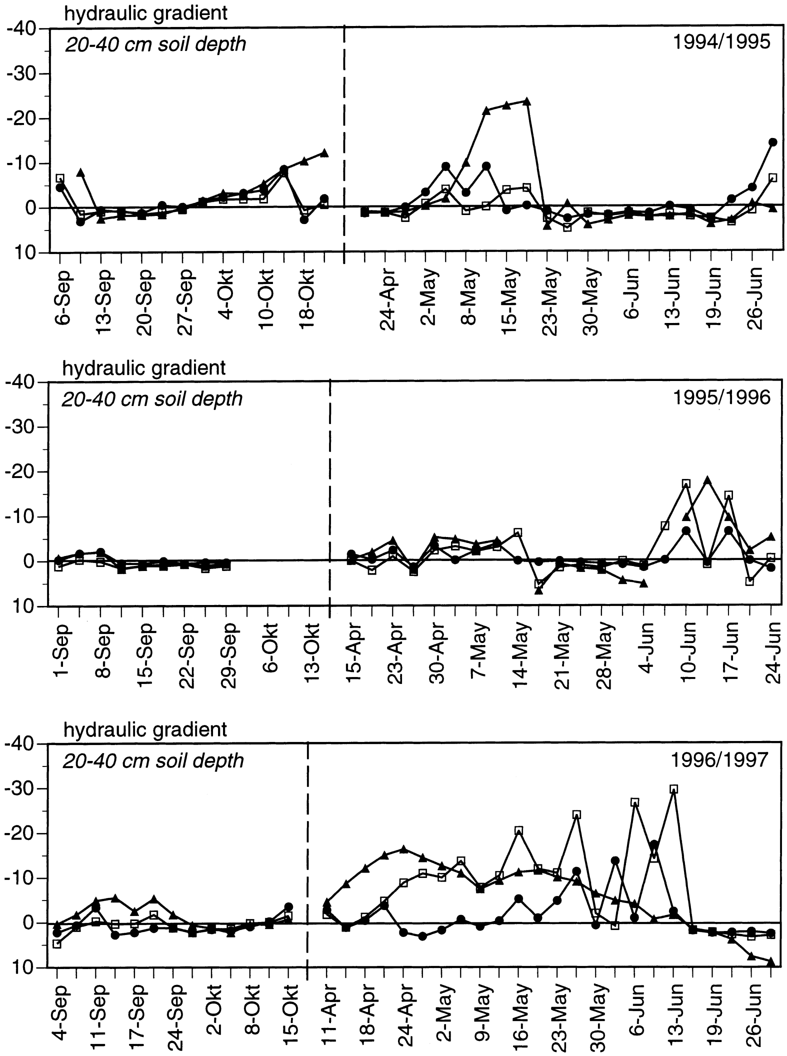

Fig. 6. Influence of irrigation on water movement in the soil layer at 20–40 cm depth in Elsanta plots from 1994–1997, as described by hydraulic gradients. —▲—: non-irrigated; —●—: tensiometer-based irrigation; and —□—: irrigation based on the climatic water balance model (cwb).

4. Discussion

In our experiment, the total quantities of water applied by irrigation were influenced by the climatic conditions, but seemed to be independent of the schedule used. However, when considering the two cultivars, it appeared that for Honeoye, the water requirements according to tensiometer measurements were

Table 5
Nitrogen content (% dry matter) in leaves of Elsanta after different irrigation schedules when irrigation followed tensiometer measurements or a climatic water balance model (cwb)

Irrigation schedule	1994–1995	1995–1996	1996–1997
Non-irrigated	3.04 b	2.32 a	2.15 a
Tensiometer	3.04 b	2.43 a	2.20 a
cwb	2.94 a	2.46 a	2.13 a

Means followed by the same letter in a column do not differ significantly ($P = 0.05$).

higher than for Elsanta. There was no cultivar effect for irrigation based upon the climatic water balance model because this schedule, according to Roudeillac and Veschambre (1987), does not differentiate between cultivars. It is based on the climatic and phenological parameters for specific cropping situations. This could be a limitation for the use of such a model because it can be assumed that cultivars behave differently, according to their physiological characteristics. However, information regarding these are not available in the literature. Rossi et al. (1988) also used the same k_c values for different genotypes of day-neutral strawberries. In lysimeter studies, Gehrmann (1986) compared water consumption and the influence on crop growth in the June-bearing cultivars 'Korona' and 'Tenira'. He found that for Korona, higher water quantities led to an increased canopy and higher fruit production than for Tenira, which indicates that there should be different k_c values for these two cultivars.

In our experiment for tensiometer-based irrigation, a threshold of 200 hPa soil moisture tension was set in the center of the main rooting area of strawberries at 20 cm soil depth. In the literature, a value between 100 and 300 hPa is generally considered to be optimal for the growth of arable plants. In the past, different thresholds have been used for strawberries. In fertilisation trials on sandy soil, Hochmuth et al. (1996) used values between 50 and 150 hPa at 15 cm soil depth. Rennquist et al. (1982a,b) obtained higher yield and bigger fruits in strawberries when the plants were growing at 100–500 hPa soil moisture tension, as compared to dry conditions with a maximum of 1160 hPa at 20 cm soil depth. Despite physiological and morphological adaptation to a water stress of 700 hPa, the strawberry cultivar 'Chandler' showed a higher yield when irrigation was applied to maintain a water potential of 100 hPa (Savé et al., 1993).

In general, irrigation enhanced the yield and fruit weight of strawberries Elsanta and Honeoye, which is in good agreement with the literature (Rennquist et al., 1982a, b; Blatt, 1984; Dwyer et al., 1987; Lamarre and Lareau, 1992). It is interesting to note that, on an average, even small amounts of irrigation resulted in yield increase when the water supply was scheduled with both systems.

As has been shown, irrigation both in autumn and spring had a more positive effect on yield than irrigation in spring only. Similar results were obtained by

Naumann (1961). He reported enhanced yield under conditions of sufficient water supply in September and October for June-bearing cultivars in northern latitudes. The findings of Naumann (1964) about higher yield under irrigation in autumn as compared to spring were explained by an increase in flower bud initiation and the differentiation of the same through sufficient water during this period.

When comparing the two irrigation schedules within and between the two cultivars, it is remarkable that there are no great differences in the amount of water applied between both schedules for Elsanta. In 1996 and 1997, Honeoye required more water when irrigation was based on tensiometer measurements, as compared to the calculated values from the climatic water balance model. This larger amount of water was not reflected in higher yield, which suggests that the threshold of 200 hPa set for Honeoye to schedule tensiometer-based irrigation in our study was too low. Rossi et al. (1988) found a reduction in yield when water quantities exceeded the proper rates for optimal growth and fruit production. Further investigations should show whether higher threshold values can also be useful in order to economically optimise water input.

In general, determination of soil moisture tension was useful in detecting and describing differences between the three treatments used in this study. However, the findings represent only a first step towards the optimisation of scheduling strawberry irrigation.

The hydraulic gradients calculated from tensiometer measurements have shown that water movement, in general, was upward directed, even under irrigation. Therefore, it seems unlikely that the leaching of mineral nitrogen from the rooted area into lower soil levels occurred. This is also supported by the results of mineral nitrogen analysis, which showed no evidence for the accumulation of mineral nitrogen in the soil layer between 30 and 60 cm depth. With both schedules used under our experimental conditions, irrigation was environmentally safe with regard to the leaching of mineral nitrogen. However, the physical characteristics of different soil types must be taken into account when determining the amount of water to be given at each irrigation event.

The present study showed that the nitrogen levels in dry leaf matter were affected by irrigation in one out of 3 years only, when there was a significant decrease after irrigation based upon the climatic water balance model. This might represent a dilution effect caused by the higher yield in these plots as compared to tensiometer-based irrigation or non-irrigated strawberries. As was shown by Lamarre and Lareau (1992), high levels of nitrogen supply did not affect the yield and fruit size of the day-neutral strawberry 'Tribute' when fertilization was combined with irrigation. In contrast, Hochmuth et al. (1996) found for different day-neutral strawberry cultivars in one of 2 years that higher nitrogen fertilization applied to drip-irrigated plants had a positive influence on crop yield during the period of maximum fruit production, which led to a higher yield at the end of the season.

The threshold of 2.5% nitrogen content in dry leaf matter for optimal nitrogen supply set by Bergmann and Neubert (1988) was not reached in the last of the three cropping seasons. A possible explanation could be that no additional nitrogen fertilization was carried out in spring 1997 as compared to the previous years. Overall, the results of our experiments support the findings that no nitrogen leaching occurred under irrigation.

5. Conclusions

In general, the goal of irrigation is to optimise yield by an economical use of water, which is scheduled according to plant needs. In all three trial seasons for both schedules, the positive influence of irrigation on the yield and fruit size of strawberries in comparison to non-irrigated plants was confirmed. The study also showed the potential to optimise the irrigation of strawberries using the climatic water balance model as a decision-making tool. This model is less labour intensive and time consuming than tensiometer measurements. Values for potential evapotranspiration are offered by meteorological services to growers through modern communication systems several times a week. Besides economic aspects, the results from the analysis of different soil parameters indicate that scheduling irrigation according to both models is also environmentally safe. Further investigations should be carried out to optimise the threshold for tensiometer-based irrigation. In addition, it would be useful to determine whether cultivar-specific k_c values should be used for irrigation based upon the climatic water balance model.

Acknowledgements

We thank J. Paschold for the helpful comments on the manuscript and C. Steden for the critical revision of the English text.

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