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Effect of Shade in Minimizing Photoinhibiton of Photosynthesis of High Grown Tea (*Camellia sinensis* L.O. Kuntze) in Sri Lanka

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ABSTRACT. *The effect of Photosynthetically Active Radiation (PAR) on the rate of photosynthesis and cholorophyll fluorescence of field-grown mature tea (Camellia sinensis L.O. Kuntze) bushes was extensively studied and characterized in high elevation of Sri Lanka. The tea bushes were subjected to three shade treatments over two year period: artificial shade (30% shade, provided by black nylon netting), unshaded and shade tree (provided by Gravillea robusta L.). This paper examines the photosynthesis and related parameters when tea bushes were subjected to different radiation intensities. Rate photosynthesis and chlorophyll fluorescence of healthy, mature leaves were related to the environmental conditions over the course of the day. The effect of radiation on productivity was assessed by shoot growth and dry matter yield. Measurements were taken from dawn to dusk on bright clear days and cloudy days with two different patterns of cloud covers. On clear days, rate photosynthesis was greatest in the morning between 8:00 and 10:00 h local time. A mid day drop in rate photosynthesis observed. could be attributed to photoinhibition of photosynthesis (PI). Rate photosynthesis was significantly ($p<0.05$) lower in unshaded plants compared to the shaded. Moreover unshaded leaves had significantly lower ($p<0.05$) fluorescence ratio (F_v/F_m) around 09:00 to 11:00 h local time compared to shaded plants, clearly indicating the PI. On cloudy days PI was not apparent. No relationship could be observed with the drop in rate photosynthesis and leaf temperature, stomatal conduction and leaf water potential. The yield which indicates the ultimate effect of all the conditions throughout the year however, was significantly higher in shade tree treatments. Although under unshaded conditions PI was observed, only 4.6% of the total number of days distributed throughout the year had bright and clear days. The rest of the period received light intensities below the saturation intensity, hence the yield increase with unshaded treatment. These data confirms the importance of correct adherence to the recommended management practices in tea for high productivity.*

INTRODUCTION

Tea continues to dominate the agricultural revenue of the country and determine the overall income of the nation despite efforts to diversify exports into non-traditional items. The ever increasing demand for tea in the national and international market can only be met by augmenting tea production by planting improved clones, by increasing acreage under tea and /or by enhancing yield potential of existing and future plantations. Potential yield can be achieved by optimizing cultural practices in tea plantations. Poor shade management is one of the causes for low productivity, since

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most of the estates do not practice recommendations. Therefore, attention on shade management is of utmost importance to get higher productivity.

Rate of photosynthesis per unit leaf area (A) is determined by the characteristics of the photosynthetic machinery, including the capacity, which are not fixed by environmental conditions during growth. A is also strongly influenced by environmental conditions, such as irradiance, temperature and nutrient supply, so that A changes diurnally and seasonally. Thus productivity is a complex function of plant characteristics and environment (Lawlor, 2001). As described by Mohotti and Lawlor (2002), field grown mature tea at high elevation of Sri Lanka, secured progressive decrease in A during the morning, as radiation, leaf temperature and vapour pressure deficit increased, which was not restored in the afternoon as they decreased. The intensity of radiation is regarded as important because of photoinhibition (PI) (Smith *et al.*, 1993). PI decreases the capacity for A in many perennial plants (Baker and Bowyer, 1994), including coffee, mango (Damian *et al.*, 2002) and several annuals such as dwarf bean (William *et al.*, 1995) and maize (Haldiman *et al.*, 1996). A central question remains however, of the impact of PI on crop growth and productivity. Moreover, shade favors partitioning of dry matter among different organs. Based on the preliminary studies conducted (Mohotti and Lawlor 2002) shade will increase or maintain A, and minimize PI in leaves of tea compared to full solar radiation.

This hypothesis was tested in mature, clonal tea growing in the field and subjected to different shade treatments (shade tree, artificial shade-30% and unshaded) over a two-year period. Measurements on A, stomatal conductance (g_s), leaf temperature (T_L), intercellular CO_2 concentration (C_i), chlorophyll fluorescence, were related to environmental conditions over the course of the day, in three different climatic conditions. The effect of radiation on productivity during the experimental period was assessed by dry matter (yield). The long term, practical aim of the work was to describe and analyze the effects of different environmental factors on photosynthesis of tea to guide development and adherence of agronomic practices for increasing crop productivity and harvestable yield.

MATERIALS AND METHODS

Experimental site

The experiment was laid out with tea bushes of cultivar TRI 2025 in field number 8 at St Coomb's Estate, Tea Research Institute, Talawakele, Sri Lanka (latitude 6^0 55' N, longitude 80^0 40' E and altitude 1382 m above mean sea level). The experimental treatments were applied in March 1996. Measurements were taken during March 2002 to January 2003.

Treatments

Treatments consisted of three levels of irradiance as follows: (a) T_1 – artificial shade, approximately 70% of incident PAR (b) T_2 - Unshaded treatment receiving full solar radiation, which on clear days was a maximum of 2000 μ mol m^{-2} s^{-1} of Photosynthetically Active Radiation (PAR) and (c) T_3 -Shade provided by *Grevillea robusta* L. 90% of incident PAR. The plots were approximately 16 m^2 area containing about 28 plants. In the shade tree plot, the tree was in the middle of the plot. The treatments were arranged in a Randomized Complete Block Design (RCBD) with three replicates.

The measurements were taken on days with different climatic conditions. Three categories were selected to represent clear and cloudy days and based on the light intensity. They were named A (bright, clear days with no clouds), B (overcast sky with clouds from time to time throughout the day) and C (overcast throughout the day, with no bright sunshine) for the easiness of discussion. Under each category, measurements were repeated at least for four similar days, which were taken as replicates for analysis.

Weather data

Weather data (sunshine hours and temperature) were obtained for the whole experimental period. The above mentioned categories (A, B and C) were selected on the basis of similar conditions for at least 4 consecutive days. A summary of the same is given in appendix.

Measurements

Rate of photosynthesis and chlorophyll fluorescence were measured on day with different climatic conditions: i.e., A, bright and clear days with average PAR of 2000 μ mol m^{-2} s^{-1}, B, intermittent overcastting with maximum of 1000 μ mol m^{-2} s^{-1} and C, ranging 100-500 μ mol m^{-2} s^{-1} over the day. In addition yield for the study period was taken.

Rate of photosynthesis

Water vapour and CO_2 exchange of the leaves were measured in healthy, mature leaves at ambient CO_2 concentration (approximately 360 μ mol mol^{-1}) using a portable photosynthesis meter (model: LI-6200, Li-cor inc., USA). Measurements were taken from 5.30 am to 7.30 pm at two h intervals. Two similar leaves on top of the canopy were used in each treatment. All the measurements were made when the leaves were enclosed in the chamber.

Chlorophyll fluorescence

Chlorophyll-a fluorescence of photosystem II (PSII) was measured using a portable modulated fluorescence meter (model OS-100, OSLOG-PP Systems, Hitchin, Herts, UK), along with the photosynthesis measurements. Similar leaves to those used for photosynthesis were taken for the fluorescence measurements. (F'o) was estimated using Fo, Fm, Fs, and F'm (Baker, 1981). The Fo and Fm measurements were taken after a period of at least 45 minutes in complete darkness. When fluorescence reached a steady-state (Fs) in leaves exposed to actinic light, a saturating light pulse was applied to obtain the maximal fluorescence under actinic light (F'm).

Yield records

Yield was recorded in each plot separately according to the plucking interval, practiced at St. Coomb's estate. The flush was dried at 95°C overnight until it reached a constant dry weight and extrapolated for a ha.

Data analysis

Data were analyzed using SAS statistical package and the means were separated using Duncan's Multiple Range Test.

RESULTS AND DISCUSSION

Photo synthetically Active Radiation (PAR)

PAR increased towards midday in category A with a peak around 11:00 to 13:00 h local time in all three shade treatments (Figure 1 A). However, the plants that were unshaded received significantly higher ($p<0.05$) PAR during the course of the day. In Figure 1 B, PAR distribution of day category B is presented. Two peaks could be observed around 9:00 h and 13:00 h in all the treatments. Unshaded plants had significantly ($p<0.05$) higher PAR only at 9:00 h. Artificial shade plots recorded the lowest PAR distribution through out the day. In the day category C (Figure 1C), PAR in all shade treatments remained at low intensities throughout the day, the maximum reached in the unshaded treatment around 700 μ mol m^{-2} s^{-1} around the 13:00 h. There were no clear peaks and there was no significant difference between the treatments.

Artificial netting provided lower ($p<0.05$) PAR in all day categories and it was significant on clear days. In most instances, the unshaded plots recorded highest light intensities.

Rate of photosynthesis (*A*)

In general, shade tree treatment had highest *A* than unshaded and artificial shade treatments in all three day categories (Figures 2A, 2B and 2C). *A* of unshaded plants was significantly lower ($p<0.05$) compared to both shade treatments during midday (Figure 2A). With days of intermittent cloud cover too, the unshaded *A* was (16%) lower than the shaded plants (Figure 2B). On the contrary, on fully overcast days, artificial shade plants had the lowest *A* throughout the day (20% reduction than the other two treatments), although not statistically significant (Figure 1C).

On average, day category A had 16% lower *A* in unshaded plants compared to shaded. Similarly, day category B with intermittent overcastting *A* was 16% lower in unshaded than shaded plants. On the contrary, day category C, with complete ovecasting over the day had 20% reduction of *A* in artificial shade treatment compared to unshaded and shade tree plots. In clear days, however, there was a 50% reduction in light saturated *A*, at 9:30 h in unshaded treatment compared to shaded, indicating PI.

This indicates the reduction of *A* could be attributed due to various factors. For example, large PAR flux causing photoinhibition (PI), high temperature inhibiting metabolism, or large VPD decreasing g_s and restricting the flux of CO_2 in to the leaf, or decreased mesophyll conductance for CO_2 in flux to the chloroplasts. There was no significant correlation of *A* and stomatal conductance in all three day categories. Moreover, leaf temperature was not significant among the treatments (data not shown). According to the above results it was so apparent that variation of *A* was positively correlated to PAR. Higher PAR during midday had a depression of light saturated photosynthesis in unshaded treatment. However, lower PAR through out the day did not show this midday depression in unshaded plots. Further reduction of PAR showed lower A in artificial shade treatment indicating that excess shade cause reduction of photosynthesis. As explained earlier it was apparent that A of mature tea grown in high elevation of Sri Lanka increased by provision of adequate shade. Radiation plays a major role in A of tea crop thus indicating PI under excess light.

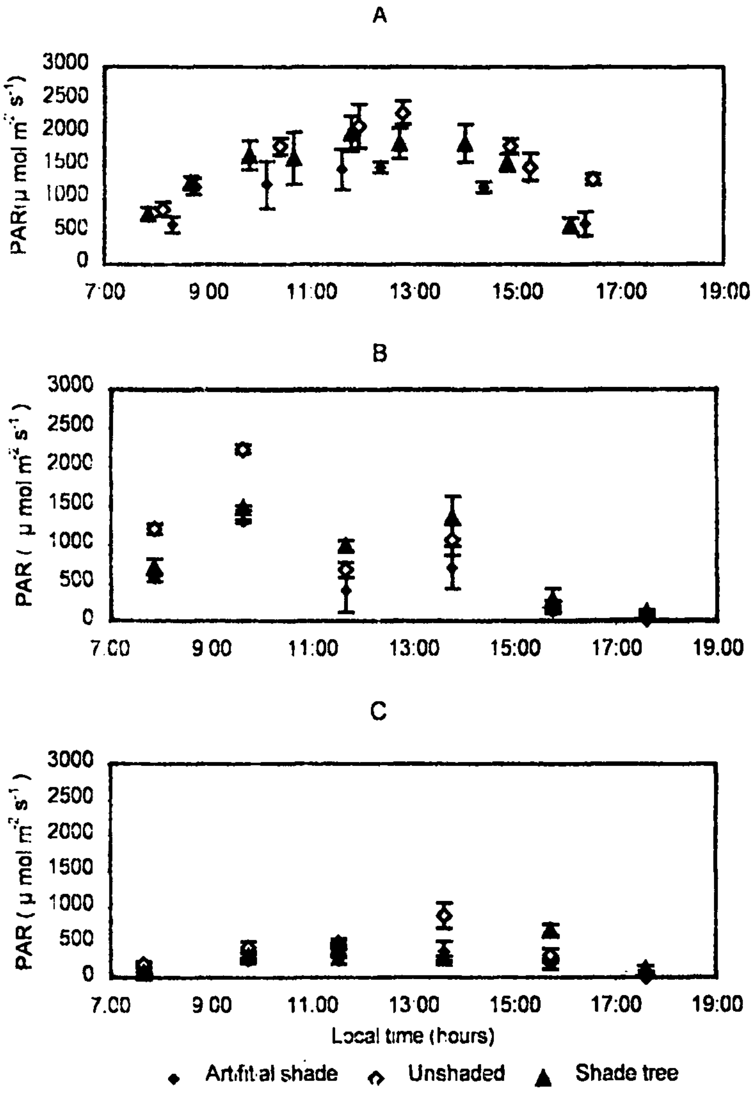

Fig. 1. Diurnal variation of PAR for tea grown in unshaded, artificial shade and shade tree (*Grevillea robusta*) for day categories of A, B and C. (The mean data are given for three replicates and vertical and horizontal bars indicate standard deviation of means).

Fluorescence

The fluorescence measurements determined from the tea leaves growing in different shade treatments were different among artificial shade, unshaded and shade tree plants. The diurnal cause of variation in fluorescence ratio (Fv/Fm) followed a midday depression with typical Fv/Fm of 0.8 in the early morning (5:30 h) and late afternoon (18:30h) in three day categories.

Under day category A, shaded treatment had slightly higher Fv/Fm than unshaded, treatment in the early morning, although not significant. During peak of PAR (11.00-13.00 h) there was 8-10% reduction of Fv/Fm in artificial shade and shade tree treatments and unshaded plants recorded 18% reduction. There was a significantly lower ($p<0.05$) Fv/Fm ratio (0.69±0.054) at 11:00 –13:00 h local time (Figure 3A). Moreover, in shaded treatment Fv/Fm recovers when PAR decreases in the evening reaching 0.8, but not in unshaded treatment (o.75). Even after a night period, Fv/Fm remained the same in unshaded treatment and did not reach the values of shaded treatment. Drop in *A* in unshaded palnts coincided with drop in Fv/Fm, thus indicating definite PI.

In day categories B and C, the mid day drop is more than 0.05 from the pre-dawn measurements with no difference between treatments. The drop in *A* was not due to PI. It has been reported that when leaves of coffee plants grown at PAR of 150 μ mol m^{-2} s^{-1} were exposed to a PAR flux of 1500 μ mol m^{-2} s^{-1}; photosynthetic capacity was decreased by 40% after 3 h, Fv/Fm decreased. Both tea and coffee are species adapted to shade in the wild state, therefore, sensitivity to larger PAR flux is expected. The sensitivity of mature tea, which might be expected to adjust to large PAR flux as coffee (Ramailho *et al.*, 1997) is in agreement with other observations (Barman *et al.*, 1993), who reported from Tocklai, India, that *A* was 33% higher for shaded than unshaded tea plants. From the present analysis, the effect is likely to be a result of smaller PAR flux and thus PI. Young leaves, even those uppermost in the canopy did not suffer chronic photoinhibiton at peak irradiance. Examination of kinetics of recovery from potentially photoinhibitory conditions indicated that dark-adapted Fv/Fm was suppressed over a lag period, but these decreases were relatively small and diminished in the line with the change in irradiance.

Photochemical efficiency was transient, and reversed as the irradiance declined again (Murchie *et al.*, 1991). Results of current study explain, there is a statistically significant effect of shade (PAR) on light saturated carbon accumulation (*A*) of tea crop. These results apparently explain the previous work done by (Mohotti, 2002) in the same experimental site. In a related study conducted by (Barman *et al.*, 1993) also suggests that basic productivity of tea, in the conditions characteristics of the main tea growing areas of Sri Lanka, would benefit from shade.

Moreover, photosynthetic efficiency Fv/Fm followed the midday depression with typical values in the early morning (5:30 h) and in the late evening (18:30 h). Unshaded leaves during clear and bright days had significantly lower ($p<0.05$) Fv/Fm around 9:00 h to 11:00 h local time. The reduction of Fv/Fm during sunny days in midday is 18%. These results resemble that midday depression of Fv/Fm is an indication of lower photosynthetic efficiency. Therefore photoinhibiton is apparent in high PAR of high grown tea in Sri Lanka. Although photoinhibition occurs during clear bright days this was not apparent under cloudy conditions.

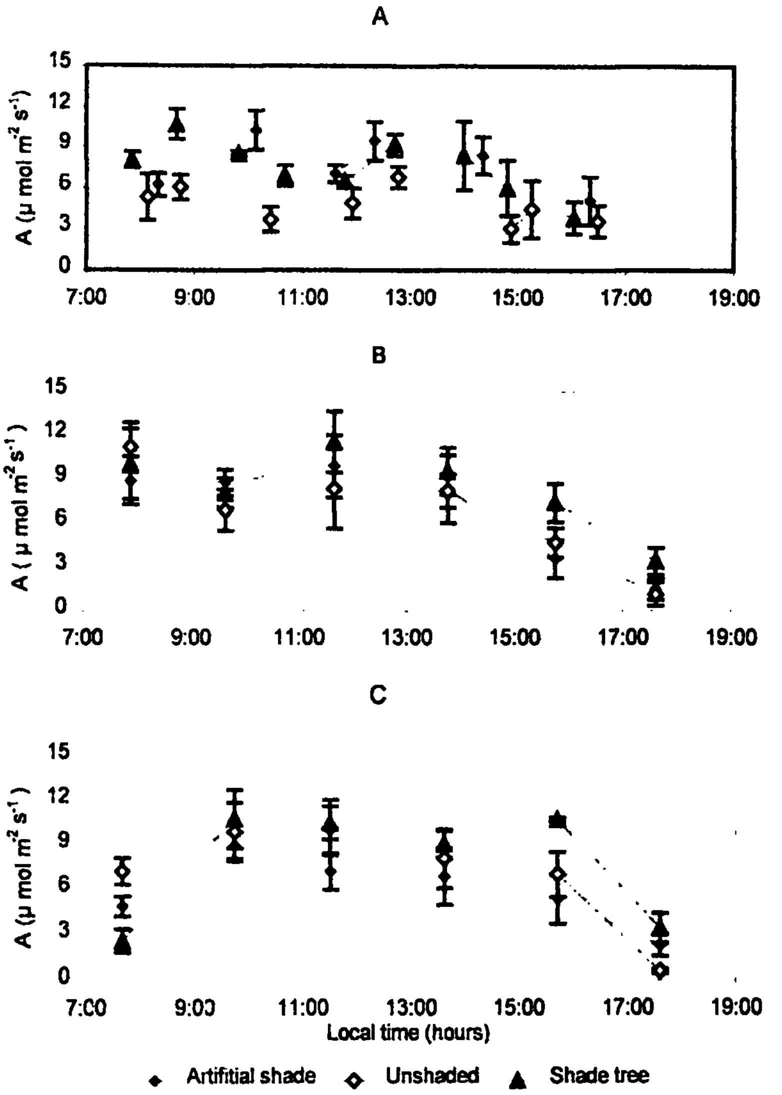

Fig. 2. **Diurnal variation of photosynthesis (*A*) for tea grown unshaded, under artificial shade, and shade tree for day categories A, B, and C.** (The mean data are given for three replicates and vertical and horizontal bars indicate standard deviation of means).

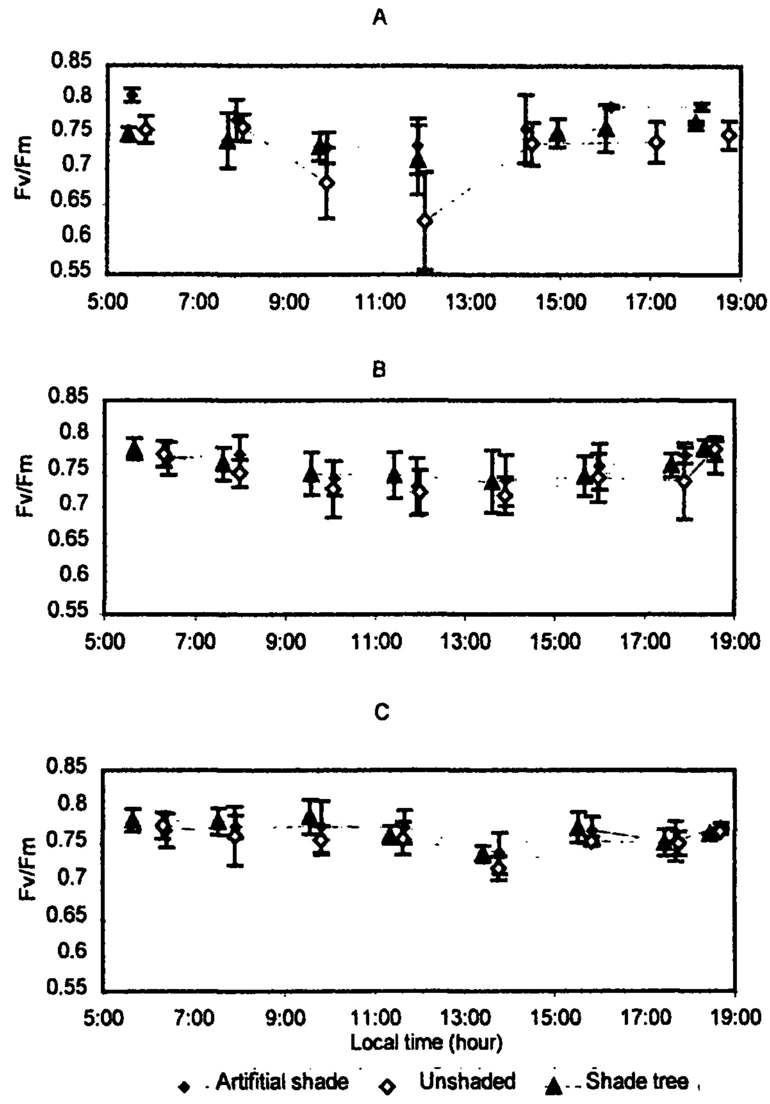

Fig. 3. **Changes of fluorescence ratio (Fv/Fm) during the day, measured during photosynthesis measurements of the leaves grown unshaded, under artificial shade, and shade tree for day categories A, B and C.** (The vertical and horizontal bars indicate standard deviation of means).

Dry matter production

Dry weight of plucked shoots for one-year period (year 2002) is illustrated in Figure 4. Shade tree plots had significantly higher ($p<0.05$) dry weight compared to unshaded and artificial shade treatments. There is a 42% reduction of dry matter yield in unshaded plants compare to shade tree. Artificial shade recorded 51% lower dry matter, indicating the loss of yield due to excess shade.

In a related study conducted by William *et al.* (1995), excessive PFDS causing PI of photosynthesis and manifested in reduced vegetative growth. These results are consistent with those of Orgen and Sjostrom (1990) who estimated Willow leaves to have lost at least 10% of the potential carbon acquisition through PI.

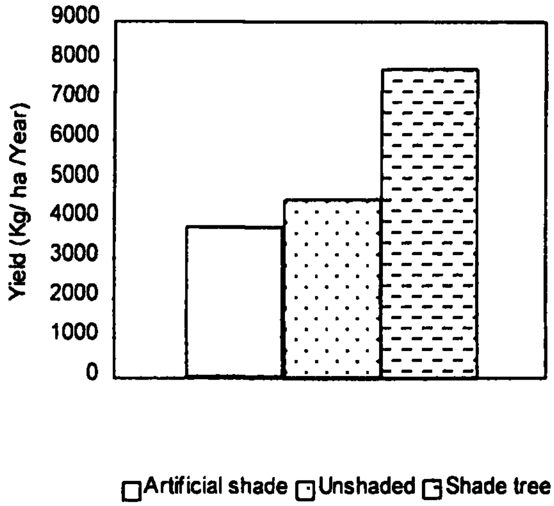

Fig. 4. Yield (kg ha^{-1} year^{-1}) of tea grown unshaded, under artificial shade and under shade tree from March 2002 to February 2003.

CONCLUSION

Mature tea grown in high elevation of Sri Lanka, showed photoinhibiton under high radiation during clear bright days. However, PI was not observed under cloudy conditions in the same experimental site. Therefore minimum shade management should be practices considering the prevailing weather conditions in a given environmental site.

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Appendix 1. Weather data during the experimental period

Year	Month	Minimum Temperature °C	Maximum Temperature °C	Sun Shine hours
2002	January	11.20	24.98	5.97
2002	February	12.57	26.42	7.07
2002	March	12.23	27.36	0
2002	April	14.10	26.07	0
2002	May	15.77	24.73	3.88
2002	June	15.71	23.01	3.90
2002	July	15.85	22.10	2.63
2002	August	15.39	22.68	3.76
2002	September	14.39	25.70	3.89
2002	October	12.23	22.76	0
2002	November	11.20	24.89	2.3
2002	December	13.57	24.48	4.16
2003	January	12.20	24.6	5.38