Fruit growing research, vol. XXVIII, 2012

OSCILAȚIILE CREȘTERII ZILNICE A TRUNCHIULUI POMILOR ÎN PLANTAȚIILE IRIGATE DE MĂR DIN JUDEȚUL ARGEȘ, ÎN CONDIȚIILE SCHIMBĂRILOR CLIMATICE
DAILY STEM GROWTH PATTERN IN IRRIGATED APPLE ORCHARDS FROM ARGES COUNTY IN RELATION TO CLIMATE CHANGES

E. Chitu[1], D. Sumedrea[1], Cr. Paltineanu[2], N. Tanasescu[1]
[1]Research Institute for Fruit Growing (RIFG) Pitesti, Romania
[2]Research Station for Fruit Growing Constanta, Romania

Abstract

In terms of climate change manifested in the last 30 years in Romania (1982-2011, average data for 29 localities) and characterized by a significant increase in maximum and minimum temperatures, especially in the summer months and increased rainfall deficit, fruit trees farm efficiency is becoming increasingly dependent on strict control of water management through irrigation systems. Thus, the maximum air temperatures experienced average growth trend per decade of 0.88°C, 0.82°C and 0.70°C in June, July and August, respectively, and minimum of 0.61°C, 0.67°C and 0.75°C, in the same months. In this context, ensuring continuous easily accessible soil water content to the root system of the trees, in correlation with plant consumption, has become the most widely used measure to mitigate the negative effects of rising temperatures and rainfall deficits. One of the most accurate methods of water stress early diagnosis and monitoring in a very short step of the fruit trees growth processes is the measurement of trunk diameter variations (SDV) with electronic dendrometers. To highlight the advantages of applying the method to irrigated apple (*Malus domestica* Borkh.) plantations from the southern Romania, we have organized two experiences with Redix and Braeburn cvs. grafted on M9 in 2009-2012 period. For measurements were used DEX 100 (Dynamax) dendrometers and GP1 dataloggers (Delta-T Devices). It was found that all SDV-derived indices (maximum daily shrinkage (MDS), daily recovery (DR) and daily growth (DG) of the trees trunk between two successive days) may be used for early diagnosis of water and temperature stress. DG was significantly negatively influenced by MDS in both cultivars and in all months of the year, except in September. The Redix cv. DG was inhibited only by the MDS values greater than 0.36 mm. DG is a much less sensitive indicator of water and heat trees stress than MDS. Emergence of water stress was highlighted by two indicators: soil water tension (SMT) and water vapor deficit of the air (VPD). MDS increased with maximum air temperature (MAXT) from 18°C in Redix cv. and only from 25°C in Braeburn cv., which seems to be better adapted to heat stress than Redix cv. We highlighted for Redix cv., using multiple correlation method, the existence of strong interactions between the effects of MAXT and VPD on the one hand and SMT on the other hand, on the reduction of DG. The higher the vapour pressure deficit and maximum temperature, the lower the daily growth due to increased values in the soil moisture tension for Redix cv. in June.

Keywords: water stress, dendrometer, trunk shrinkage, recovery
Cuvinte cheie: stres hidric, dendrometru, contracția trunchiului, rehidratare

1. Introduction

Orchards, as perennial crops, are highly exposed over long periods to the negative impact of climate changes, but making the study of time, this can help growers to adapt to these risks. Compared to annual crops, whose cropping strategies can be applied relatively quickly, an orchard requires impact studies for extended periods of time. The Romania's Fifth National Communication on Climate Change under The United Nations Framework Convention on Climate Change (2010) underlines that the changes in the climate conditions in Romania are part of the global context, taking into account the regional conditions: the temperature increase is expected to be more obvious during the summer. According to the same communication, compared to the baseline (1961-1990), in January, in the 2001-2008 interval, the air temperature increased by 1.6°C, in March by 1.3°C, in July by 1.6°C and in August by 1.6°C. The increasing trend was obvious beginning with 1981.

Under these conditions the most important stress factors for apple culture in the southern part of Romania became high summer temperatures (heat waves) and lack of soil water (drought) and the most important technological measures to mitigate the negative effects irrigation. Until 10 years ago, according to FAO, irrigation scheduling based mainly on soil water balance. However, this strategy has some uncertainty, particularly in fruit trees, where calculated water application must be corrected for canopy area or for fruit load (Naor, 2006) among other factors. In the last decade, has been widely used as plant water stress indicator measurements of leaf water potential, performed with pressure chamber. Recently, was adopted stem water potential measurements due to the high sensitivity of the method to water stress and its good prediction of the yield response to deficit irrigation.

At present, research in this field is focused on the use of short period trunk diameter variations (Fernandes and Cuevas, 2010), specifically the maximum diameter stem shrinkage (MDS) and the trunk growth rate (GR), as possible substitutes for stem water potential. However, the ability of different soil or plant water stress indicators to predict crop responses to water stress has not been sufficiently compared. The feasibility of any water stress indicator should be characterized specially during the phenological periods particularly sensitive to water stress, when avoidance of even a mild plant water deficit is important to optimize crop yield like, for instance, during the fruit set, induction or of fruit growth in pome fruit species.

The objective of this work was to evaluate the ability and sensitivity of several SDV derived indices to predict the trees water stress and meteorological stress in irrigated apple plantations from Arges County, southern Romania.

2. Materials and Methods

The researches were carried out at RIFG Pitesti, southern Romania, during 2009-2012 period. The trials were established in two high density apple orchards (7 years old), one in 2009 with Redix apple cv. (*Malus domestica* Borkh.) and other in 2011 with Braeburn cv. (3,077 trees ha^{-1}) grafted on M9 rootstock. The experimental plots were placed on a flat terrain, located on the second terrace of the Arges River, the soil being a brown eumesobasic, slightly podzolic and pseudogleyc one. In terms of soil texture was sandy loam, with good aeration and water holding capacity (clay between 12.5% and 15.5%). During the testing period for both cultivars, the trees yield levels were kept constant through manual thinning (123-141 fruits per tree). The influences of the soil and weather factors were quantified using a set of indicators of stem diameter variation (SDV): maximum daily shrinkage (MDS, mm), trunk daily growth rate (DG, mm), stem recovery (SR, mm), duration of daily shrinkage (DDS, h) and duration of daily recovery (DDR, h). Soil water tension was measured at 20 and 40 cm depth in the soil along the irrigation tube and the row of trees, in two positions related to drippers: under the dripper and at halfway between drippers (50 cm). Soil moisture tension was measured with granular matrix sensors 6450WD (Watermark from Spectrum Technologies Inc., fig. 1) attached to WatchDog 400 dataloggers. The short period variations of the trunk diameter were hourly registered with linear variable differential transformer sensors (DEX 100 dendrometers, Dynamax, fig. 2) with GP1 dataloggers (Delta T Devices), with two adaptors GP-PBA-X50, used to raise the measurement precision to 0.001 mm.

DEX 100 electronic dendrometers were set on the north and upper third of the tree trunk with a stainless steel support and fastened with elastic bands. It was also taken into account, to avoid the exposure of dendrometer sensor to the influence of direct sunlight. This would induce the appearance of additional errors generated by large temperature fluctuations during sunny days. It was also chosen the upper third of the trunk to place dendrometers to avoid accidental contact of dendrometer arm by associated grasses from plantation and for its additional screening by tree foliage.

For the description of climate changes across the country, we used a database consisting of maximum temperatures (MAXT), minimum (MINT) and mean daily temperature amplitudes (MDTA) in the last 30 years (1982-2011), from 29 localities evenly distributed throughout Romania. For Mărăcineni (where the experimental field of RIFG Pitesti is located), climatological database included the last 43 years (1969-2011).

Annual and monthly means were computed for the following parameters: air and soil surface temperature (°C), the duration of sunshine (h), solar radiation (W m^{-2}), relative air humidity (%), rainfall (mm), wind speed (m s^{-2}, at 2 m height above the ground), vapor pressure deficit from the air (VPD for daily means, MVPD for daily maximum, kPa), Penman-Monteith potential evapotranspiration (mm) and the soil moisture tension at 20 and 40 cm depth (SMT, kPa). The normality of the distribution was verified for monthly or annual means of meteorological elements, using statistical tests Shapiro-Wilk and Kolmogorov -Smirnov (SPSS 14.0). When the normality assumption has been accepted, the probabilities using "NORMDIST" function from Microsoft Office Excel were also calculated. We used probability values for comparing the climatic linear trends of the 29 localities, because their annual and monthly means showed a significant variation that exceeded the significance threshold of $P \leq 0.05$ (tested with Duncan's multiple range test).

The experimental data were processed by the variance analysis, using the specialized program SPSS 14.0 with its bifactorial ANOVA calculation model and by correlation and regression methods (Pearson's and partial correlation and determination coefficients). For plotting on maps the linear trend of average temperatures increasing over 10 years, we used geostatistical kriging interpolation module of the Surfer 9.0® (Golden Software, 2009) software.

3. Results and discussions

To justify the need for generalized application of irrigation in apple orchard in Romania and water administration according to sensitive biological indicators of water trees stress early appearance, there were initially analyzed the trends in air temperature (potential evapotranspiration component) in the last 30 years.

Evolution trends of annual values of climatic parameters for the 29 stations

Figure 3 plots annual means over the period of study, for the 29 localities and for maximum temperature, minimum and daily air temperature amplitude. It was verified by correlation and linear regression method, the intensity of the relationship between the three temperatures and time.

The determination coefficients of linear equations (R^2) were compared with those of curvilinear ones (logarithmic, power, polynomial, exponential) and found that in no case approximation increase did not exceed 5%. It was observed that the growth rate of maximum and minimum air temperatures in Romania in the last 30 years (1982-2011) is nearly equal: 0.48ºC per decade for minimum and 0.49ºC for maximum. Degree of statistical assurance of these trends was higher for minimum temperatures. Thus, 41.4% of the minimum temperatures variation can be attributed to the time factor, while for the maximum, only 24.3% (R^2 = 0.243 **). In the same 30 years period, mean daily temperature amplitudes remain unchanged. If we compare the growth rate per decade, but expressed by probabilities (Fig. 4), we see that the minimum temperature had a higher trend (21.7% in a decade) than maximum (17.0% in a decade). Also, in the case of probabilities, statistical assurance level of these trends is higher for minimum temperature versus maximum.

Spatial distribution of the annual mean temperatures trends

These trends are shown in Figures 5 and 6. These are maps made by geostatistical kriging interpolation using the Surfer 9.0 (Golden Software) program. They delimit areas with linear trends per decade of equal intensity for maximum, minimum and mean daily temperature amplitudes. It was observed that the minimum temperature increasing rate is more uniform in the area (one location not statistically assured, Bucharest-Baneasa) than the maximum (four locations statistical uninsured, i.e. Buzau, Craiova, Grivita and Drobeta Turnu Severin). It has been noted that there is a zone higher heating rate, both in the South and in the North-Eastern Romania (Bistrita and Targu Mures). To the south-west of Romania the situation has been different: although MINT (Figure 6) has been growing fast, MAXT increasing rate has been reduced (Figure 5). There have been also identified two areas with significant increases in the mean daily temperature amplitudes centered on Targu Mures and Bucharest Baneasa.

The increasing trends for mean annual temperature values at Maracineni

The increasing linear trends of mean, minimum and maximum air temperatures for Maracineni, county Arges, where the research was conducted, are shown in Figure 7. The increasing rate of temperature was continuously and relatively uniform, like the average situation for Romania: the average temperature rose by 0.35°C per decade and had a higher degree of statistical assurance (R^2 = 0.4035 ***) than the extreme temperatures (R^2 = 0.2495*** for maximum and R^2 = 0.1337*** for minimum ones but all highly significantly affected by time variable).

The increasing trends in mean monthly temperature for Romania and Maracineni

The information presented in Table 1 is very important because it gives us the time of year where MAXT and MINT grow significantly. It is noted that in general, the level of significance of linear trends of growth over 10 years of maximum and minimum temperature was low during winter, spring and autumn. It was, however, very high (significance = sig. probability between 0.01 and 0.001) for June, July and August. The degree of assurance for MINT growing rate was higher (level of significance (P) of less than 0.003) than for MAXT (sig. probability between 0.001 and 0.046). MDTA trends are not statistically assured for any month of the year. MINT growth was determined by time, in percentages between 26.7% in July and 44.5% in August.

The same sharp warming trend for summer months was noted for Maracineni too. If in the first decade of climatological records for Maracineni, 1969-1978 (Fig. 8), the mean air temperature was 9.4ºC and rainfall deficit of only 86 mm (located in July and August), in the last decade of records 2002-2011, the annual mean temperature increased by 1.1ºC (10.5ºC) and rainfall deficit almost doubled reaching to 159 mm and spread over 5 months (April-August).

These conditions require the implementation of specific "precision" technological measures to ensure positive interaction of all factors and vegetation conditions, biological, chemical and physical, balanced allocated and with quantitatively and qualitatively optimized levels.

Trunk diameter micro-oscillations as early indicator of water stress status of trees

When the transpiration starts early morning due to water loss from the leaf surface, it creates a tension in xylem vessels of all organs of the plant. A portion of the water stored in plant tissues during the night is lost, allowing the plant to respond quickly to the rapid changes in the atmosphere water vapor deficit. This process affects every organ of the plant that stores water so that the diameter changes in all organs, including stems, branches, roots and fruits. Changes in the water content of extensible tissues of the stem are readily reversible, causing diurnal SDV. For fruit trees, the water stored in the trunk contributes substantially to leaves transpiration. Also, water from xylem vessels and living tissue surrounding the xylem is extracted and used in transpiration process, so trunk diameter decreases.

Trees trunk diameter variations (SDV) derived indices used for irrigation application scheduling can be calculated from hourly recorded values of SDV. There are three distinct phases in a typical oscillation cycle of trunk diameter on summer days (Hinckley and Bruckerhoff, 1975; Lassoie, 1979; Antonova et al., 1995, cited by Fernandez, J.E., Cuevas M.V., 2010)(Fig. 10):

- Contraction phase defined as the period during which trunk diameter decreases, usually based on a maximum recorded early in the morning until after noon minimum. The index is called the maximum daily shrinkage (MDS) and expressed in millimeters (maximum trunk diameter minus minimum diameter of the day) and the phase duration – daily duration of shrinkage (DDS), expressed in hours;
- rehydration phase, which is the period of the diurnal cycle when the trunk diameter increases from the daily minimum until it reaches to the maximum of the next day morning. The index is called daily recovery (DR) and is expressed also in mm (maximum trunk diameter minus minimum diameter of the previous day) and the phase duration – daily duration of recovery (DDR, expressed in hors);
- growth phase, defined as the period during which trunk diameter continues to increase until the beginning of the following day contraction. The index is called daily growth (DG), is expressed in millimeters and is equal to the diameter of the day minus the diameter of the previous day. Some days when the trees are in severe water stress no longer has a trunk growth phase, DG values are even negative.

An example of the rapid diagnosis of early water stress condition by determining micro-oscillations of trees trunk diameter is shown in Figure 11. It can be seen that in the period 14 to 17 June, soil water tension was very low (below 20 kPa) due to daily drip irrigation, given that both temperature and direct solar radiation values were very high (daily values of air temperature between 25 and 30ºC) and constant (Fig. 11a). Tree trunk diameter reaction was swift, with an increasing in daily growth (DG), but also by reducing the values of maximum daily shrinkage (MDS). Since the 17th of June until 21st of June, temperature and solar radiation have similar conditions to the previous period, soil water tension exceeded 20 kPa (higher retention forces of soil water by interrupting daily watering), daily trunk diameter growth decreased and maximum daily shrinkage values increased, reaching almost double the previous period.

The hourly measurements database of the trunk diameter of the two apple trees cultivars grafted on M9, processed by us, consisted of 470-490 days in 3 years (2009-2011) for Redix cv. and 216-218 days in two years (2011 -2012) for Braeburn cv. By processing the daily values of SDV- derived indices of the trunk, calculated from hourly values recorded in the April to October period, resulted all graphs presented below.

There are three stages of data processing: analysis of monthly dynamic of SDV-derived indices and the study of the intensity of temporal determination by analysis of variance, analysis of correlative links between trunk diameter micro-variations derived indices, among them, using correlation matrices, and finally determining environmental factors that exert the most intense action on SDV-derived indices and the development of models to estimate their impact on SDV indices.

Monthly dynamics of SDV-derived indices

In Figures 12 and 13 can be observed that DG is heavily influenced by the time of year where measurements were performed. Thus, the highest values of daily trunk growth were recorded in May and June, for both Redix cv. (0.068 to 0.073 mm, fig. 12), and Braeburn cv. (0.057 to 0.047 mm, Figure 13). Unlike Braeburn, in Redix daily diameter growth values remain high in July and August. DG lowest values were recorded both in April and in September and October. In both cultivars, the year of study had little influence in changing differences between months. Maximum daily trunk diameter shrinkage had the highest values in July and August for Redix cv. (0.442 mm and 0.427, fig. 14), and only in July in Braeburn cv. (0.289 mm, fig. 15).

The strength of the correlation of SDV-derived indices between them

In the figures 16 to 19, we analyzed the correlations between SDV-derived indices, but also between them and the months of the year. Has been shown, especially in Braeburn cv., the negative correlation between DG and MDS (fig. 16, r = -0.246*). Also, daily trunk growth rate depended more (r = -

0.277* in Braeburn cv. and r = -0.242*** in Redix cv.) than the maximum daily shrinkage (in Braeburn cv. r = -0.143 and r = 0.134* in Redix cv.), on the period of the growing season. Therefore, by modeling the oscillation dependence of these indices of environmental factors, we used regression equations for each month from March through September.

We checked in Fig. 18 and 19, using polynomial regression equations of the second degree if the two main SDV-derived indices (DG and MDS, DR being excluded because its autocorrelation both with DG, and especially with MDS) are mutually interrelated. The Redix cv. correlation was significant only in June, July and August. Until MDS values of approx. 0.36 mm or DG was unchanged with increasing of MDS, like in July and August or increased slightly as in June. At MDS values higher than 0.36 mm in all three summer months was a strong negative correlation, the more pronounced slope being recorded in June. In Braeburn cv. the two SDV-derivate indices were significantly negatively correlated (and almost linear) in all months analyzed, except September when the correlation was positive. The most intense depressive effect of DG, induced by the increase of MDS values, was recorded in May and June (R^2 = 0.1785* and R^2 = 0.1637** respectively).

The influence of meteorological factors and soil water potential on SDV-derived indices

In Figure 20 we tested the sensitivity of DG to the oscillation of MVPD for each month separately. MVPD as stated by many authors (Goldhamer and Fereres, 2001, Fereres and Goldhamer, 2003, Intrigliolo and Castel, 2006, Ortuno et. al., 2006a, b, and Conejero et al., 2007, Fernandez and Cuevas, 2010), is one of the most used meteorological factors with great influence on SDV-derived indices (especially on DG and MDS). It can be seen from the figure that for Redix cv., the influence of MVPD on DG was insignificant in all months analyzed, except September. The same weather factor (MVPD) but correlated with MDS, was highly significantly positive for all months of the growing season (Fig. 21). Particularly intense was influenced MDS in both cultivars, by the maximum daily temperature values (Figures 22 and 23). There is a big difference between the two cultivars in terms of maximum temperature, from which MDS values began to increase rapidly. Thus, if the Redix cv. MDS values rise above 0.15 mm, almost uniformly to 0.65 mm started from 18ºC (Fig. 22), in Braeburn cv. the growth of MDS is felt only started from maximum temperatures values over 25ºC (Fig. 23). We can say that Braeburn cv. seems more adapted than Redix cv. to the water loss from the tissues caused by high temperatures, even with good soil water supply.

To determine which one of environmental factors has the greatest influence on SDV-derived indices, we made graphs from Figures 24 and 25. It is observed that with small differences between cultivars, the highest values of Pearson correlation coefficients were recorded primarily for MDS and much weaker for DG. Environmental factors that have the greatest influence on MDS were: maximum air temperature (r = 0.798*** in Redix cv. and 0.669*** in Braeburn cv.), VPD (r = 0.612*** for Redix cv. and 0.684*** for Braeburn cv.) and ETo-PM (r == 0.608*** for Redix cv. and 0.675*** for Braeburn cv.). A significant influence had also average and minimum air temperature, solar radiation and soil water tension.

In Figure 26 we represented for Redix cv., using multiple regression equations, the influence of SMT, measured at 20 cm depth, on the DG variation. The most significant downward trend of DG with increasing values of SMT occurred in June and July.

In Figure 27, we also highlighted using the multiple correlation method for Redix cv., in July (month in which there is most pronounced water stress), the strong interaction between the influence of MAXT and MVPD on the one hand and SMT on the other hand on the values of DG (Fig. 27). Applying multiple regression equation with interactions, we compiled the resulting graph from Figure 28. In this graph, the more MVPD (0.4 to 4.0 kPa) and MAXT (15-35 ° C) had higher values, the DG decline was more intense with increasing values of SMT (0-30 kPa). The practical consequence of this finding is very important. To avoid rapid depression of Redix cv. DG values in July, during periods with MAXT and MVPD very high values, we must maintain soil moisture steadily high, i.e. a constant SMT at very low levels (below 10 kPa), possibly by applying the second daily irrigation.

4. Conclusions

Under the conditions of continuous warming trend over the past 30 years in Romania, and the sharp rise in the rainfall deficit during the summer months, growing trees in high density systems require the application of more efficient methods of irrigation. Our study evaluates the possibility of using SDV-derived indices and their sensitivity in estimating the early thermal and water stress in irrigated apple orchards from Arges County;

All SDV-derived indices can be used for early diagnosis of water and temperature stress, the conditions under which errors caused by variations in fruit production and for DG caused by vegetation season are eliminated. Because of the difficulties of calculation, DDS and DDR are recommended to be used with caution.

DG depends on the period of growing season much more than MDS and therefore for modeling the stress state monthly equations will be used. The highest values of DG were recorded in May and June for both cultivars: Redix cv. (0.068 to 0.073 mm) and Braeburn cv. (0.057 to 0.047 mm);

MDS showed peaks in July so for Redix cv. (0.443 mm) and for Braeburn cv. (0.289 mm).

DG was a much less sensitive indicator of water and temperature stress (SMT, VPD and MVPD) than MDS. DG was significantly negatively influenced by MDS in both varieties and in all months of the year, except in September. For Redix cv., DG was inhibited only by MDS values greater than 0.36 mm.

MDS increased with MAXT, started from values of 18ºC in Redix cv. and only from 25ºC in Braeburn cv., which seems to be a more adapted cultivar to the heat stress.

It was highlighted by multiple correlation method, the existence of a strong interaction between the influence of maximum temperature and vapour pressure deficit on one hand and the soil moisture tension on the other hand, as regards the reduction of daily growth. The higher the vapour pressure deficit and maximum temperature, the lower the daily growth due to increased values of the soil moisture tension for Redix cv. in June. The practical consequence of this finding is very important. To avoid rapid depression of Redix cv. DG values in July, during periods with MAXT and MVPD very high values, we must maintain a steadily high soil moisture content, i.e. constant SMT at very low levels (below 10 kPa), possibly by applying the second daily irrigation.

5. References

1. Conejero, W., Alarcon, J.J., Garcia-Orellana, Y., Abrisqueta, J.M., Torrecillas, A., 2007. Daily sap flow and maximum daily trunk shrinkage measurements for diagnosing water stress in early maturing peach trees during the post-harvest period. Tree Physiology 27, 81–88;

2. Fernandez, J.E., Cuevas M.V., 2010. Irrigation scheduling from stem diameter variations: A review. Agricultural and Forest Meteorology 150 (2010) 135–151;

3. Fereres, E., Goldhamer, D.A., 2003. Suitability of stem diameter variations and water potential as indicators for irrigation scheduling of almond trees. Journal of Horticultural Science and Biotechnology 78 (2), 139–144;

4. Goldhamer, D.A., Fereres, E., 2001. Irrigation scheduling protocols using continuously recorded trunk diameter measurements. Irrigation Science 20, 115–125;

5. Intrigliolo, D.S., Castel, J.R., 2006. Usefulness of diurnal trunk shrinkage as a water stress indicator in plum trees. Tree Physiology 26, 303–311;

6. Naor, A., 2006. Irrigation scheduling and evaluation of tree water status in deciduous orchards. Horticultural Reviews 32, 111–165;

7. Ortuno, M.F., Garcia-Orellana, Y., Conejero, W., Ruiz-Sanchez, M.C., Mounzer, O., Alarcon, J.J., Torrecillas, A., 2006a. Relationships between climatic variables and sap flow, stem water potential and maximum daily trunk shrinkage in lemon trees. Plant and Soil 279, 229–242;

8. Ortuno, M.F., Garcia-Orellana, Y., Conejero, W., Ruiz-Sanchez, M.C., Alarcon, J.J., Torrecillas, A., 2006b. Stem and leaf water potentials, gas exchange, sap flow, and trunk diameter fluctuations for detecting water stress in lemon trees. Trees 20, 1–8.

Tables and figures

Fig. 1. 6450WD sensor (Watermark, Spectrum Technologies, Inc.) and WatchDog 400 datalogger

Fig. 2. DEX 100 electronic dendrometer tied with elastic bands on tree trunk and connected to the GP1 (Delta-T Devices) datalogger

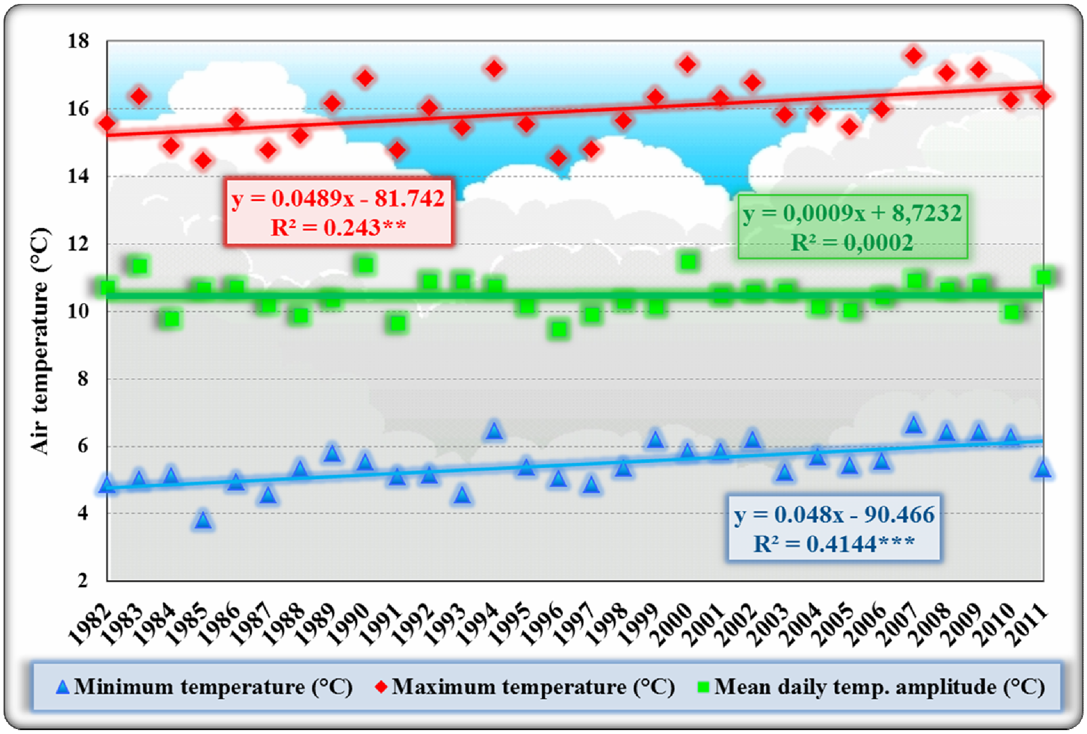


Fig. 3. Dynamics of the values of air temperature annual means over the last 30 years in Romania (1982-2011, averages for the 29 localities)

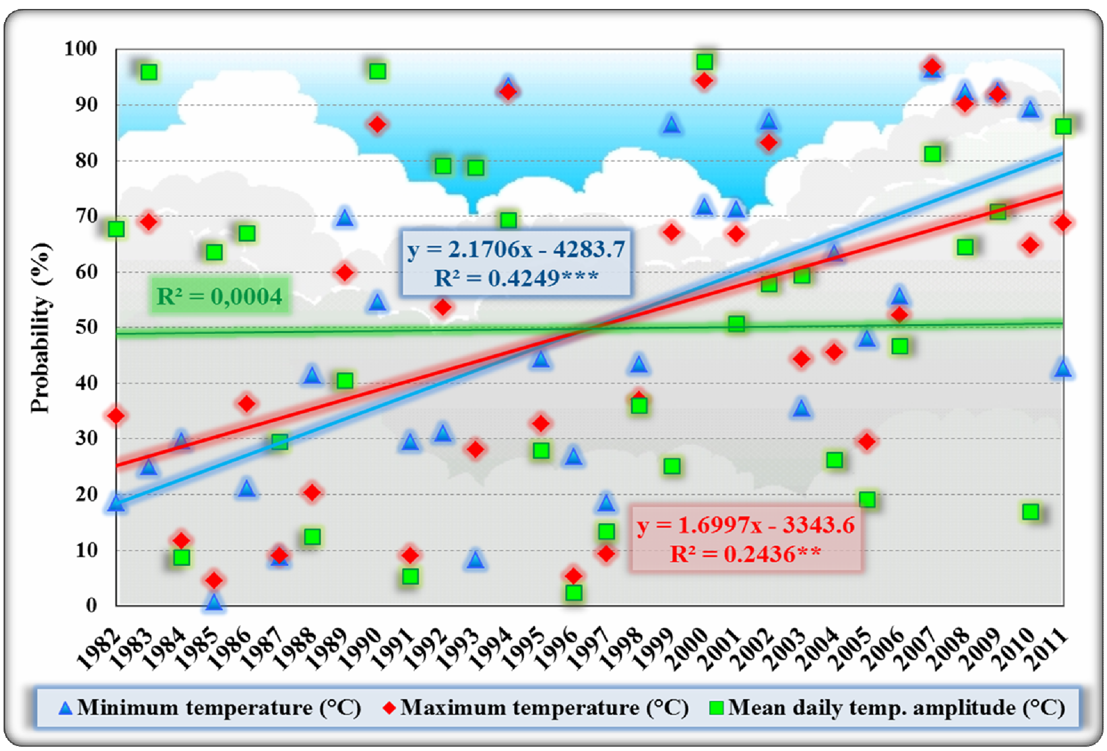


Fig. 4. Dynamics of the probabilities of annual means of air temperature over the last 30 years in Romania (1982-2011, averages for the 29 localities)

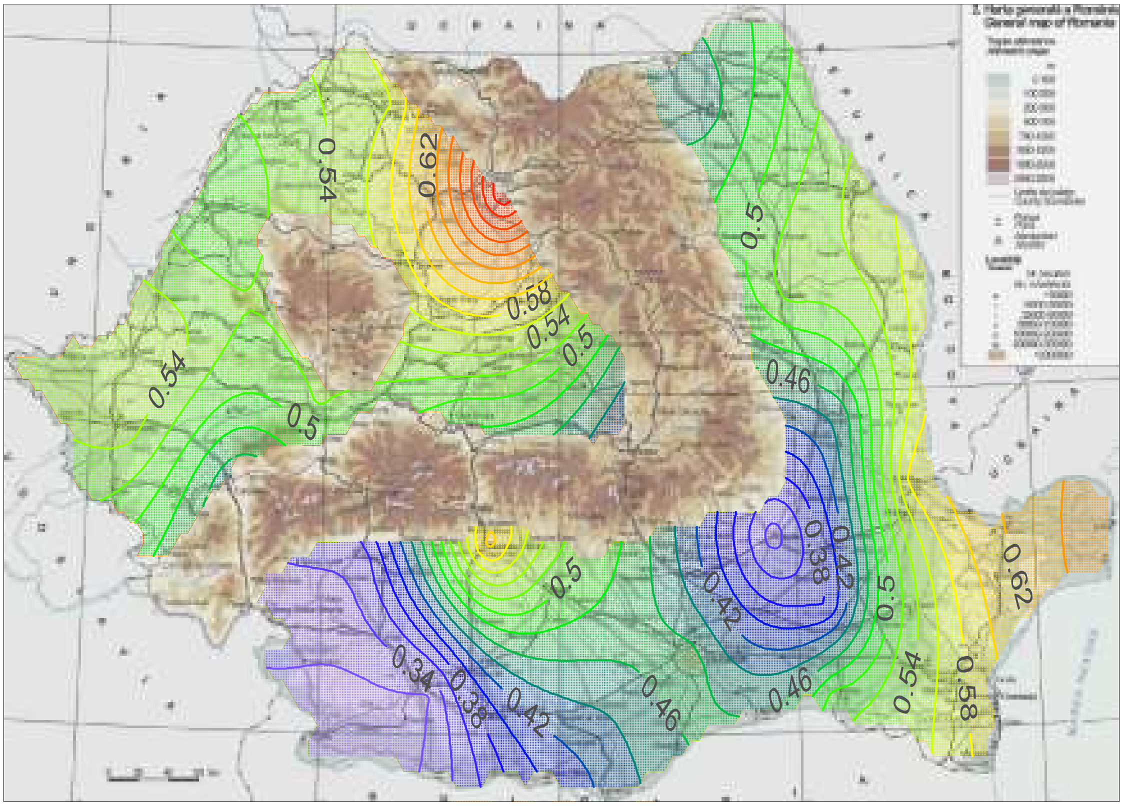


Fig. 5. Spatial distribution of the annual maximum temperature linear trends per decade in Romania over the last 30 years (1982-2011)

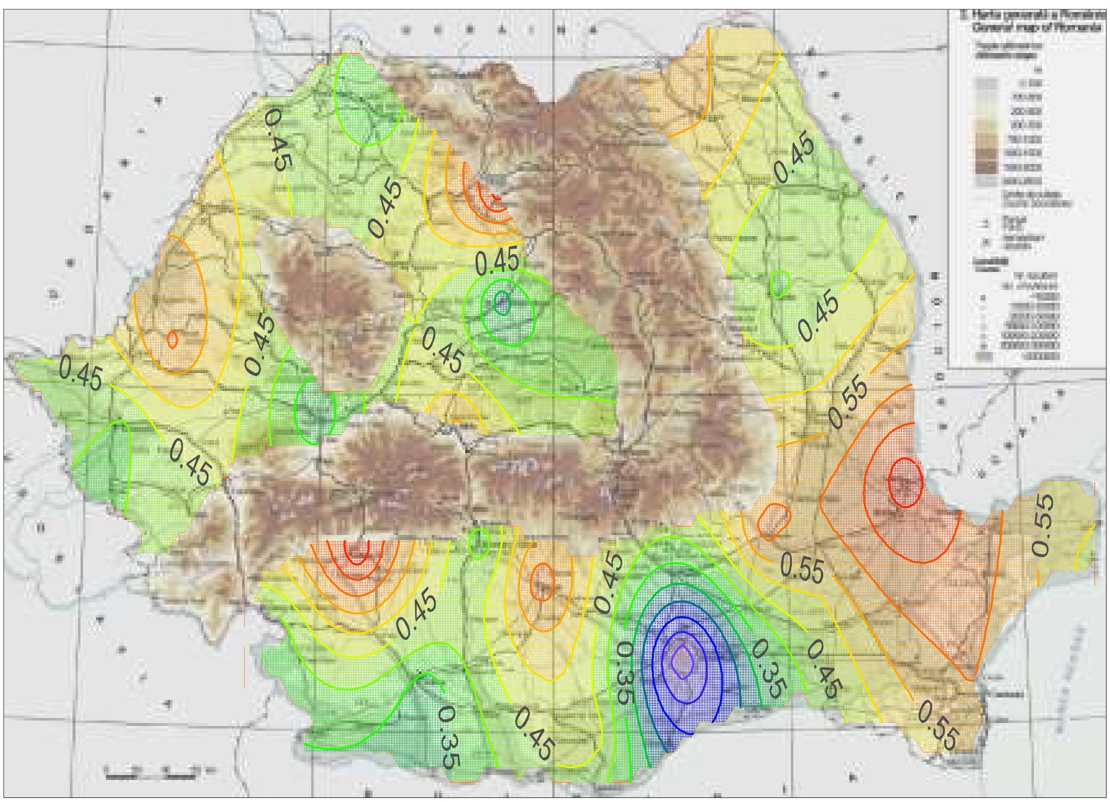


Fig. 6. Spatial distribution of the annual minimum temperature linear trends per decade in Romania over the last 30 years (1982-2011)

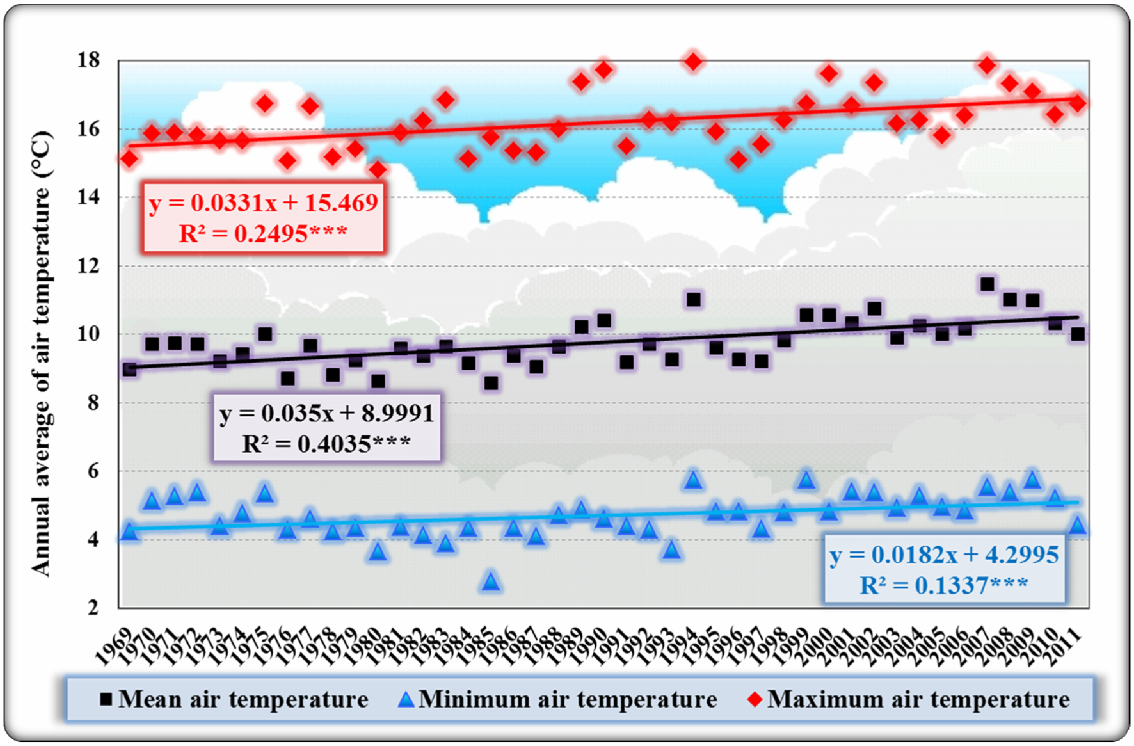


Fig. 7. Dynamics of the annual means of air temperature over the last 43 years to Maracineni - Arges (1969-2011)

Table 1. Linear regression equations indicators, which expresses the dynamics of monthly means of air temperatures during 1982-2011 (determination coefficient, significance level and average trend per decade); sig. means significance

Month	Maximum temperature (°C)			Minimum temperature (°C)			Mean daily temperature amplitude (°C)		
	R^2 (%)	Sig.	Mean trend in 10 years (°C)	R^2 (%)	Sig.	Mean trend in 10 years (°C)	R^2 (%)	Sig.	Mean trend in 10 years (°C)
January	0.1	0.869	0.09	0.6	0.680	0.22	1.6	0.509	-0.14
February	6.0	0.194	**0.90**	8.2	0.125	**0.94**	0.1	0.892	-0.04
March	5.7	0.203	**0.78**	3.9	0.298	0.41	5.2	0.225	0.36
April	3.2	0.341	0.39	3.1	0.353	0.25	1.5	0.523	0.14
May	2.9	0.365	0.34	2.3	0.421	0.18	1.8	0.484	0.17
June	**30.7**	**0.001**	**0.88**	**35.4**	**0.001**	**0.61**	6.5	0.174	0.27
July	**24.9**	**0.005**	**0.82**	**26.7**	**0.003**	**0.67**	2.1	0.444	0.15
August	**13.5**	**0.046**	**0.70**	**44.5**	**0.000**	**0.75**	0.1	0.855	-0.05
September	1.4	0.532	-0.28	4.7	0.250	0.3	11.0	0.074	-0.57
October	0.1	0.891	-0.04	4.4	0.267	0.3	7.3	0.148	-0.35
November	**13.9**	**0.042**	**1.10**	13.0	0.051	**0.94**	2.2	0.439	0.17
December	0.9	0.626	0.23	1.0	0.602	0.25	0.0	0.913	-0.02
Average	**8.6**	**0.343**	**0.49**	**12.3**	**0.254**	**0.49**	**3.3**	**0.473**	**0.01**

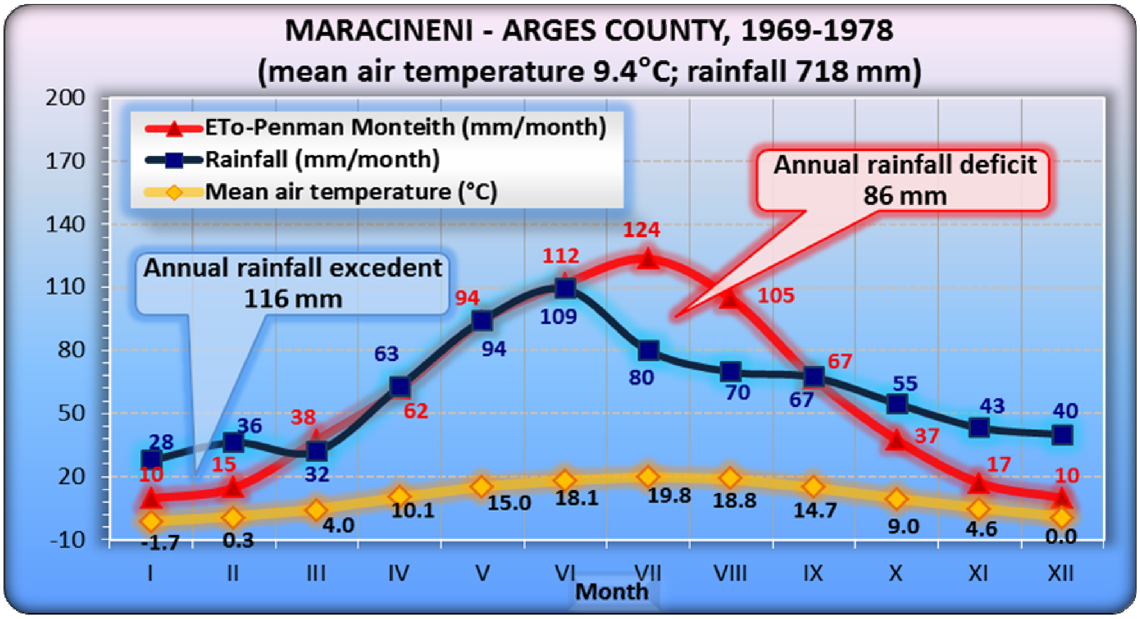


Fig. 8. Meteorological diagram of 1969-1978 decade to Maracineni, Arges county

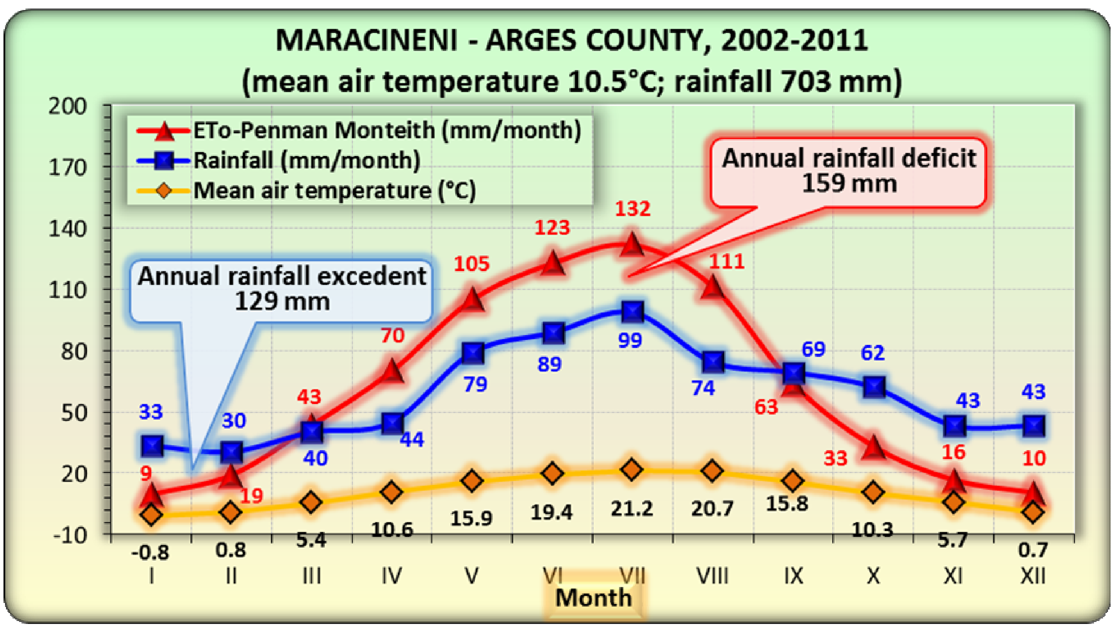


Fig. 9. Meteorological diagram of 2002 -2011 decade to Maracineni, Arges county

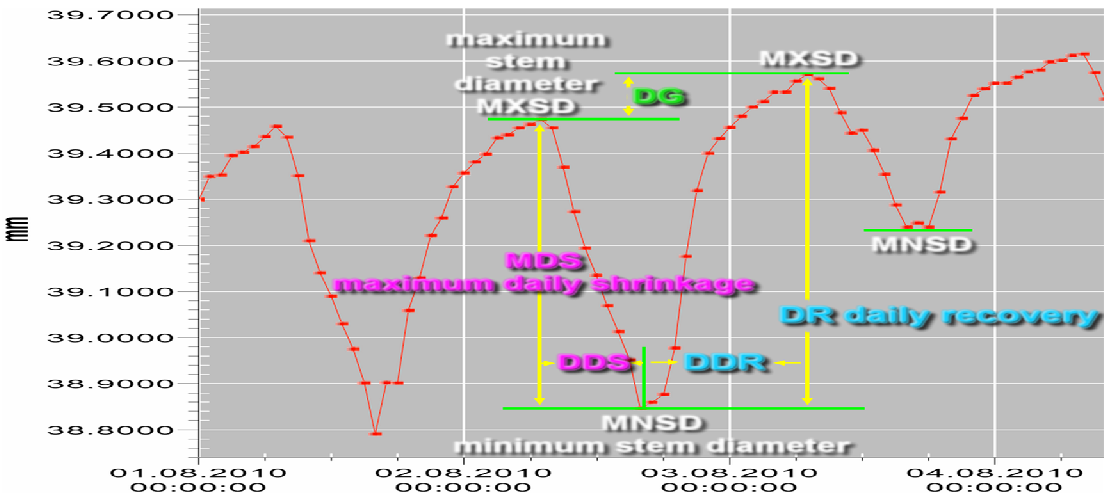


Fig. 10. Derived indices of daily tree trunk diameter micro-oscillations (Redix cv., Maracineni. 2010)

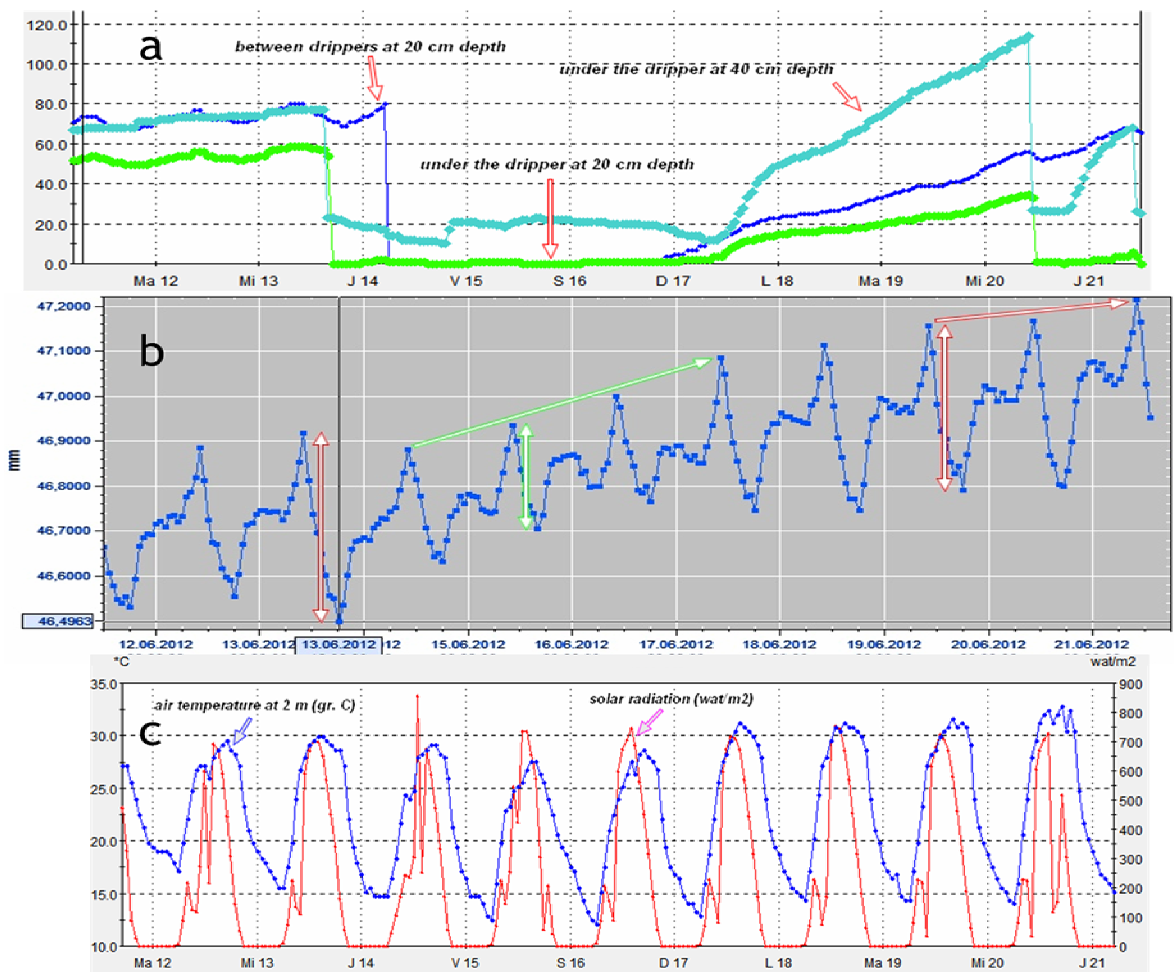
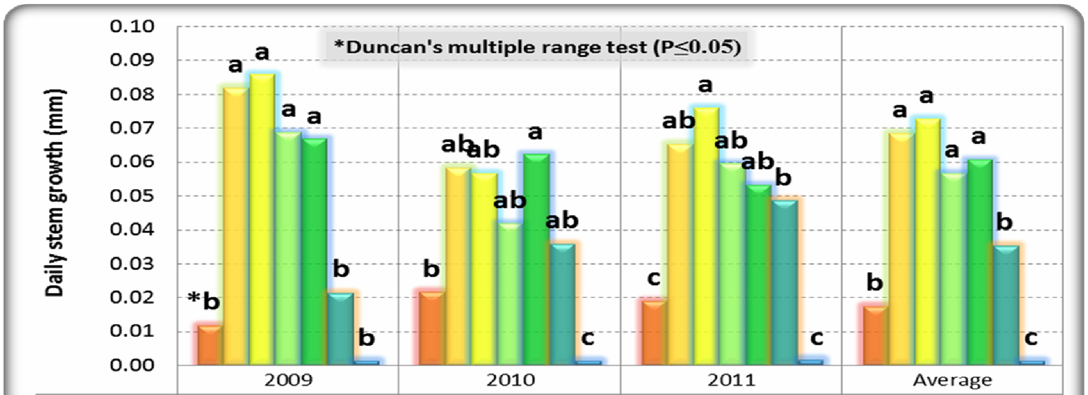
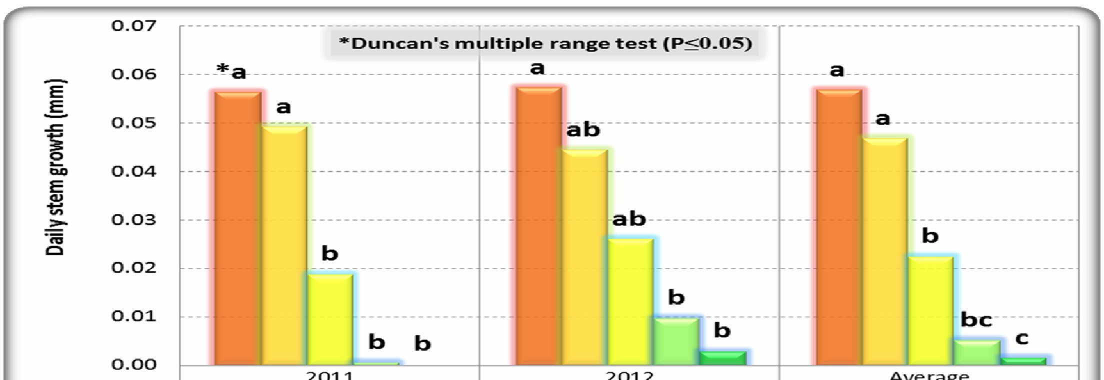


Fig. 11. Dynamics of soil water tension at 20 and 40 cm depth (a), hourly micro-oscillations diagram of Braeburn cv. trunk diameter as presented by Delta Link program 2.5.1. from Delta-T Devices (b) and evolution of temperature and direct solar radiation at WatchDog ET 900 weather station (c) within 12 to 21 June 2012 (Maracineni)



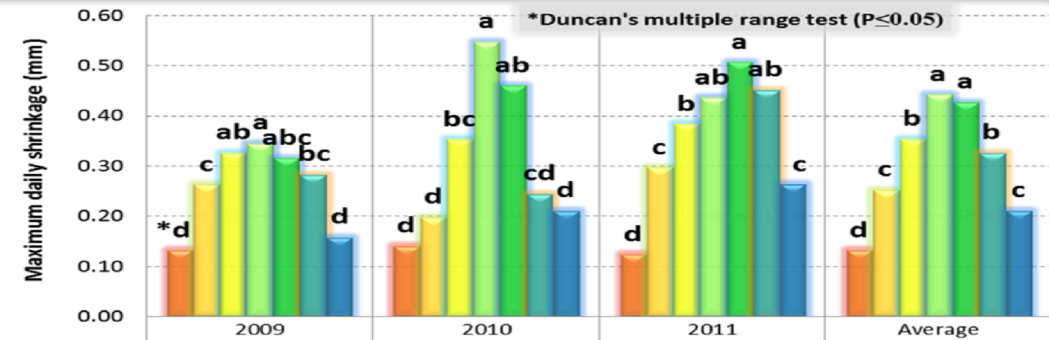
	2009	2010	2011	Average
April	0.0118	0.0216	0.0190	0.0175
May	0.0818	0.0584	0.0653	0.0685
June	0.0858	0.0568	0.0759	0.0728
July	0.0688	0.0419	0.0596	0.0568
August	0.0668	0.0622	0.0532	0.0607
September	0.0214	0.0358	0.0486	0.0353
October	0.0013	0.0014	0.0016	0.0014

Fig. 12. Influence of the month on the Redix cv. daily stem growth (DG), depending on the year of study (2009-2011)



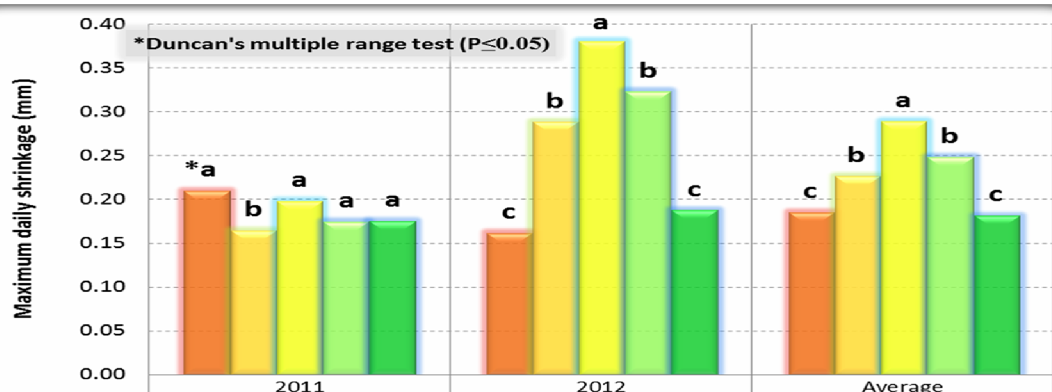
	2011	2012	Average
May	0.0563	0.0574	0.0568
June	0.0493	0.0445	0.0469
July	0.0189	0.0261	0.0225
August	0.0007	0.0099	0.0053
September	0.0003	0.0030	0.0017

Fig. 13. Influence of the month on the Braeburn cv. daily stem growth (DG), depending on the year of study (2011-2012)



	2009	2010	2011	Average
April	0.1314	0.1398	0.1229	0.1314
May	0.2629	0.1981	0.2965	0.2525
June	0.3259	0.3525	0.3830	0.3538
July	0.3448	0.5469	0.4357	0.4425
August	0.3158	0.4599	0.5063	0.4273
September	0.2826	0.2444	0.4515	0.3262
October	0.1578	0.2102	0.2626	0.2102

Fig. 14. Influence of the month on the Redix cv. maximum daily shrinkage (MDS), depending on the year of study (2009-2011)



	2011	2012	Average
May	0.2102	0.1623	0.1862
June	0.1647	0.2883	0.2265
July	0.1988	0.3797	0.2892
August	0.1751	0.3226	0.2489
September	0.1762	0.1882	0.1822

Fig. 15. Influence of the month on the Braeburn cv. maximum daily shrinkage (MDS), depending on the year of study (2011-2012)

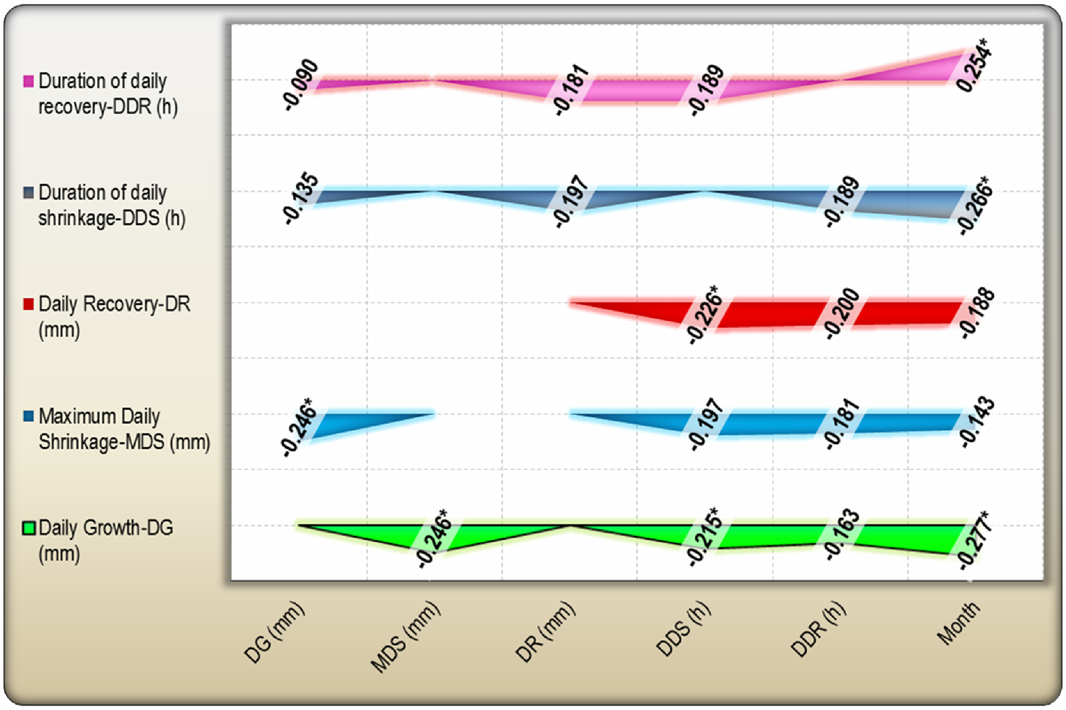


Fig. 16. Braeburn cv. correlation matrix of the stem diameter variations derived indices (Pearson's correlation coefficients, 2011-2012)

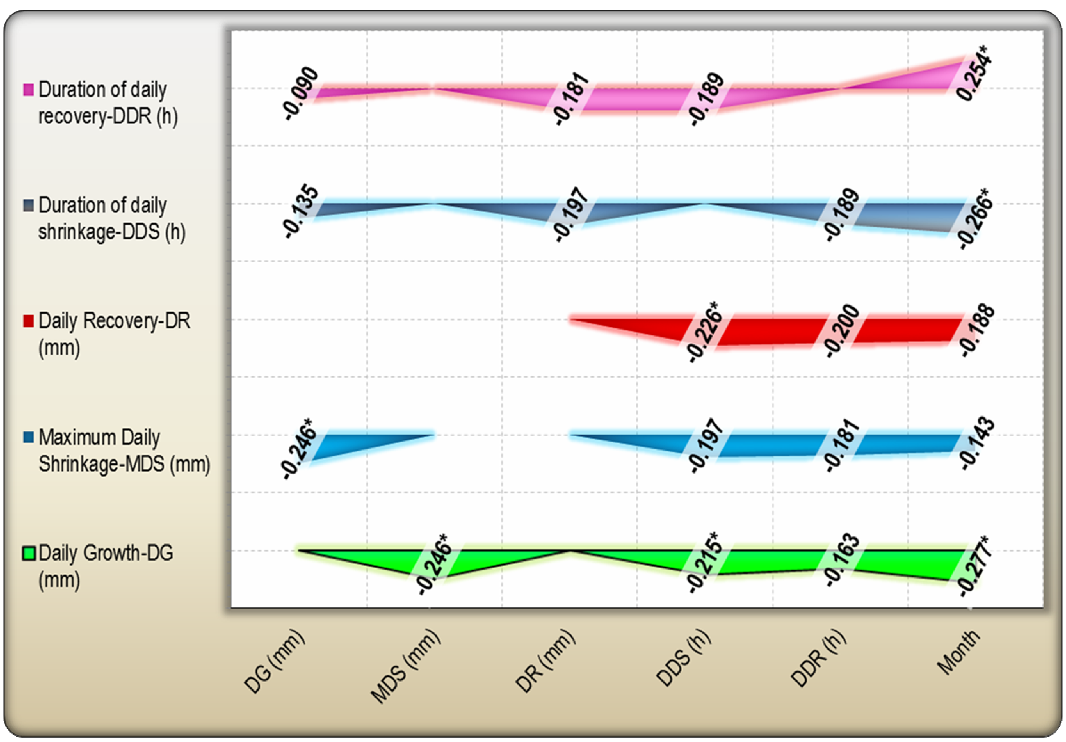


Fig. 17. Redix cv. correlation matrix of the stem diameter variations derived indices (Pearson's correlation coefficients, 2009-2011)

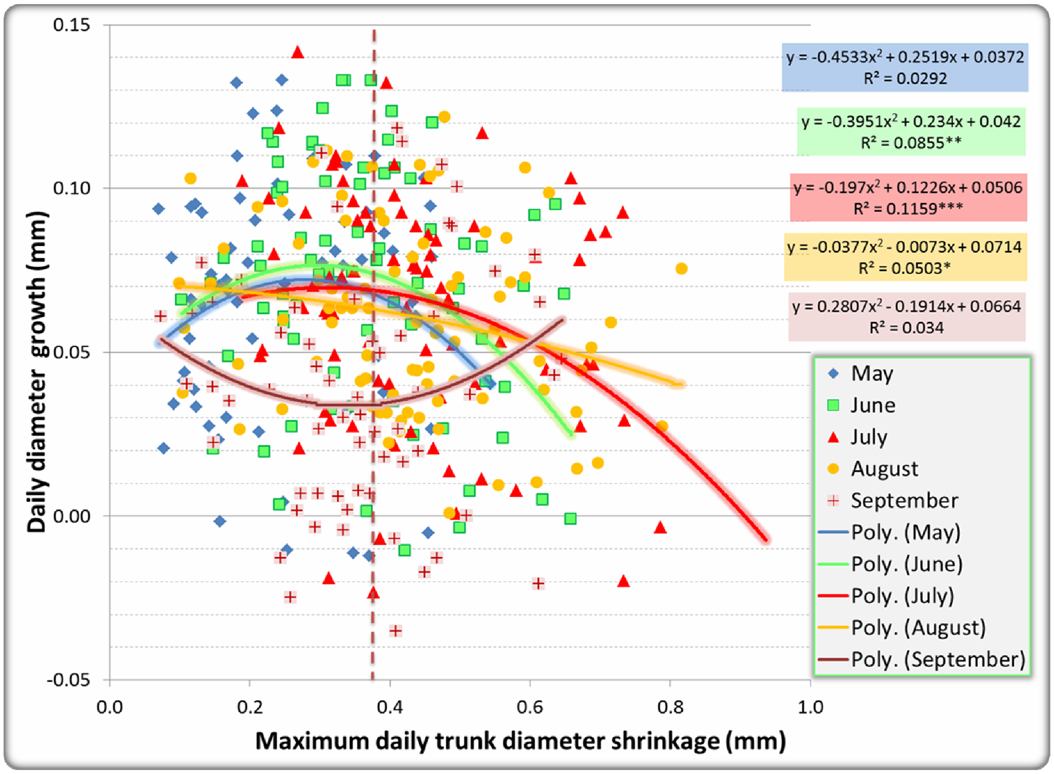


Fig. 18. The strength of the correlation and the regression curves shapes between DG and MDS of Redix cv. (determination coefficients, 2009-2011)

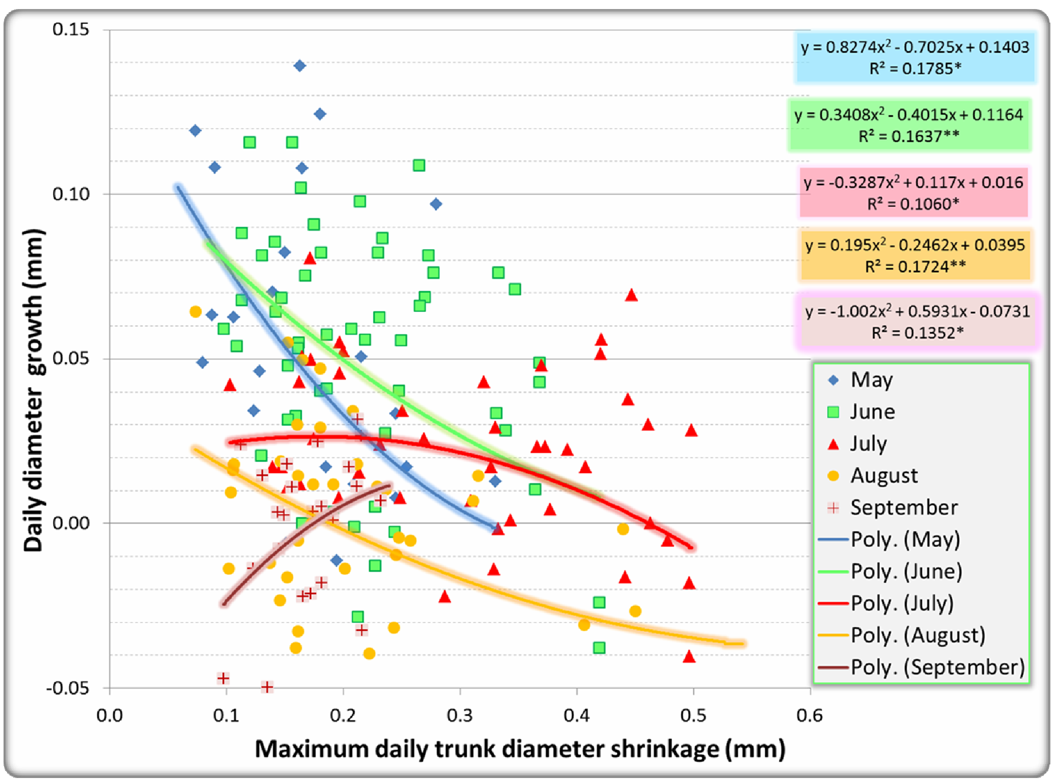


Fig. 19. The strength of the correlation and the regression curves shapes between DG and MDS of Braeburn cv. (determination coefficients, 2011-2012)

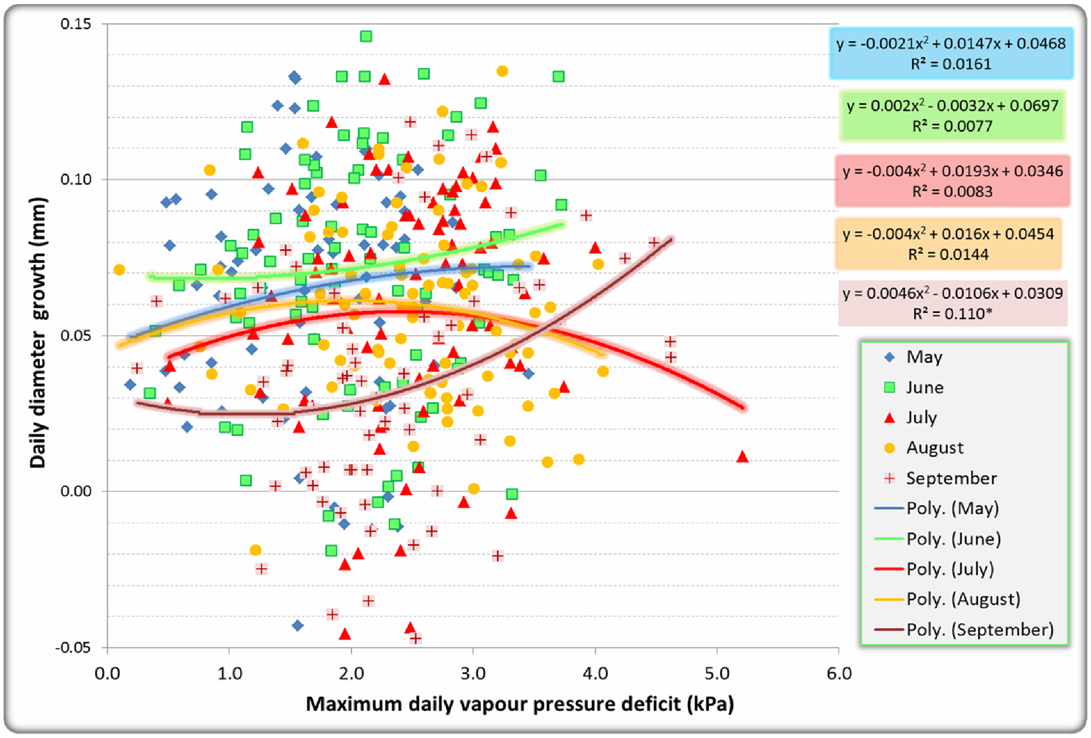


Fig. 20. Comparison between the strength of the correlation and the regression curves shapes of DG with MVPD (Redix cv. determination coefficients, 2009-2011)

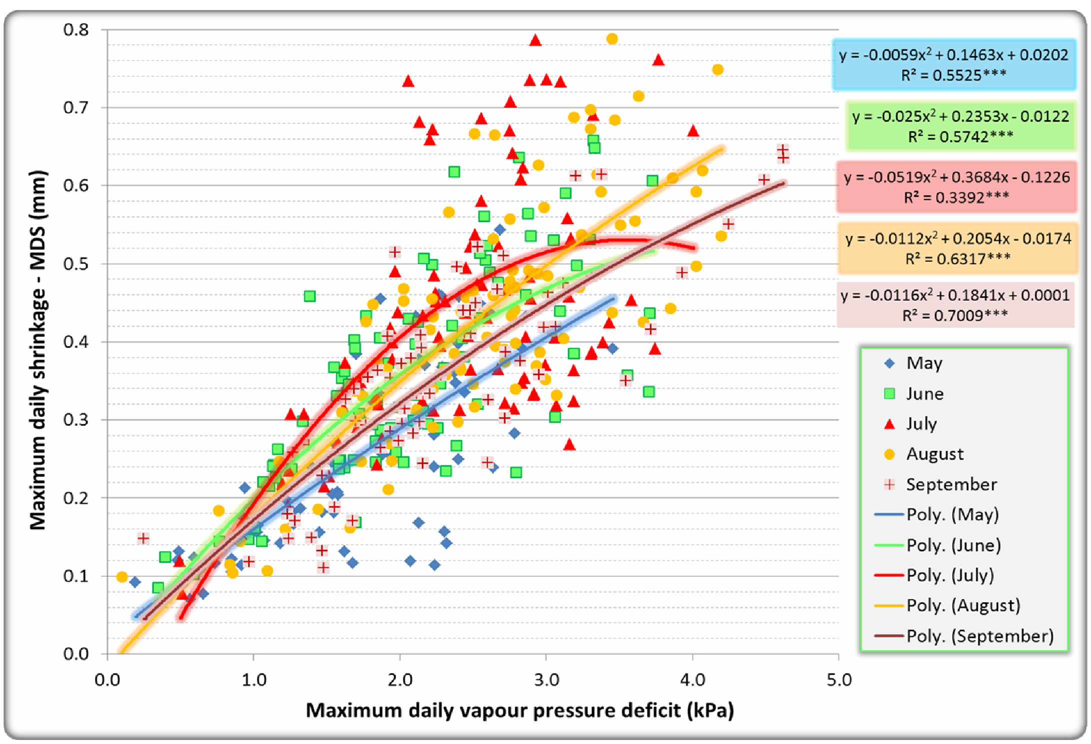


Fig. 21. Comparison between the strength of the correlation and the regression curves shapes of MDS with MVPD (Redix cv. determination coefficients, 2009-2011)

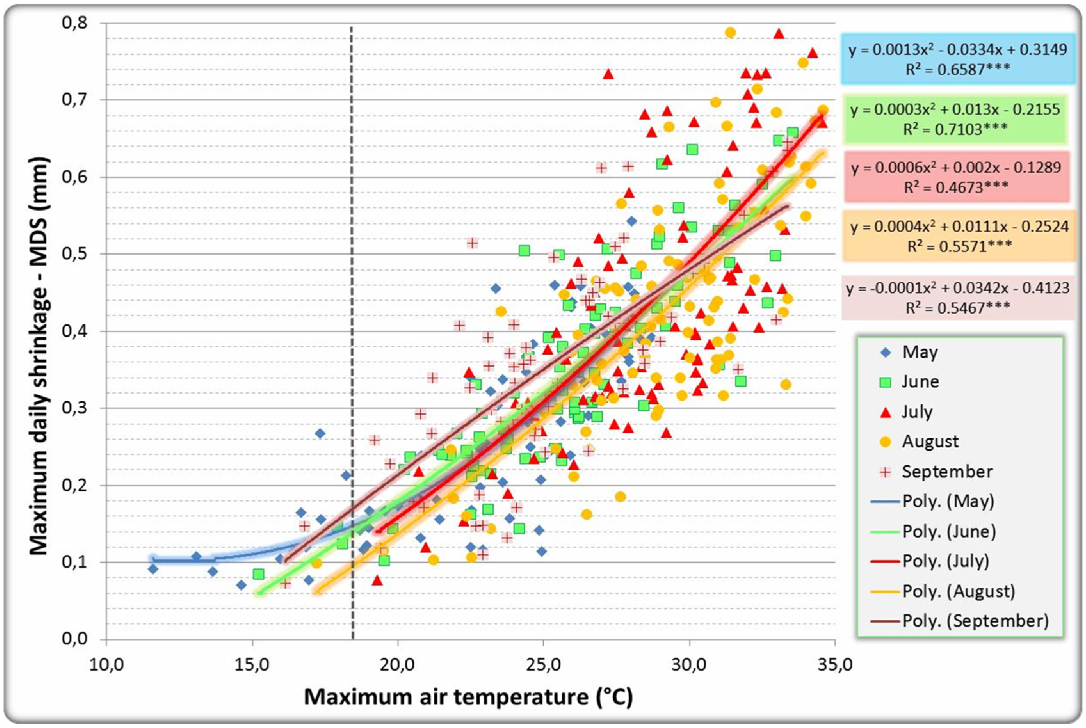


Fig. 22. Comparison between the strength of the correlation and the regression curves shapes of MDS with MAXT (Redix cv. determination coefficients, 2009-2011)

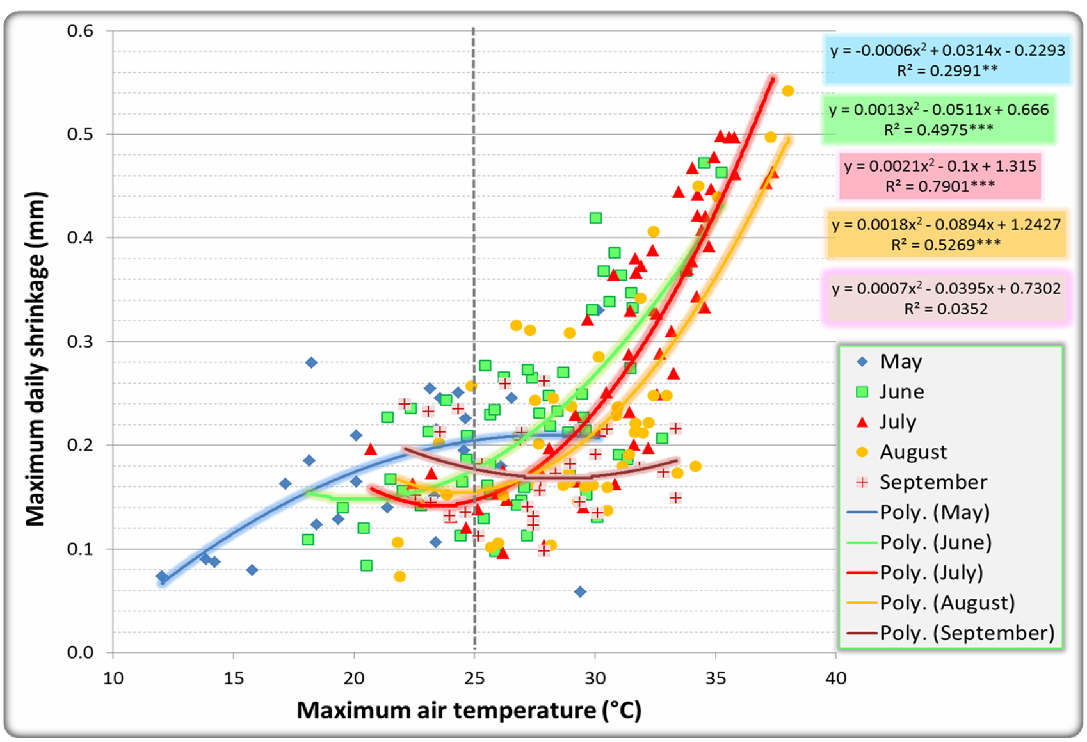


Fig. 23. Comparison between the strength of the correlation and the regression curves shapes of MDS with MAXT (Braeburn cv. determination coefficients, 2009-2011)

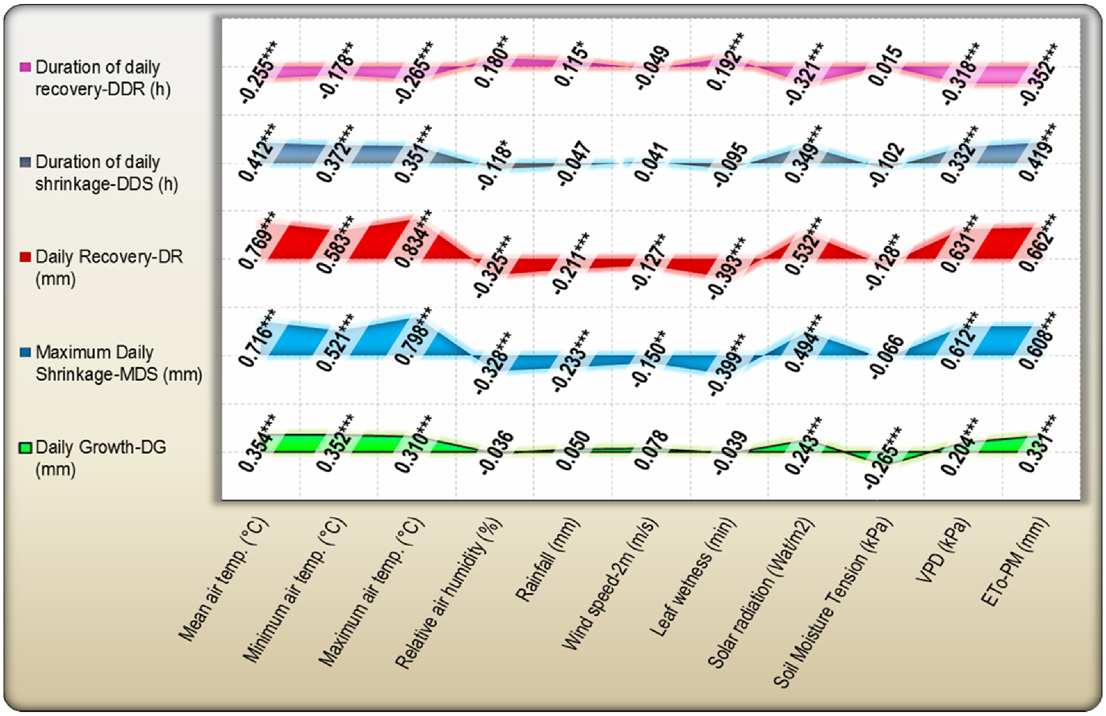


Fig. 24. The influence of the meteorological factors and soil moisture on the stem diameter variation derived indices (Pearson's correlations coefficients for Redix cv., 2009-2011 and April – October months)

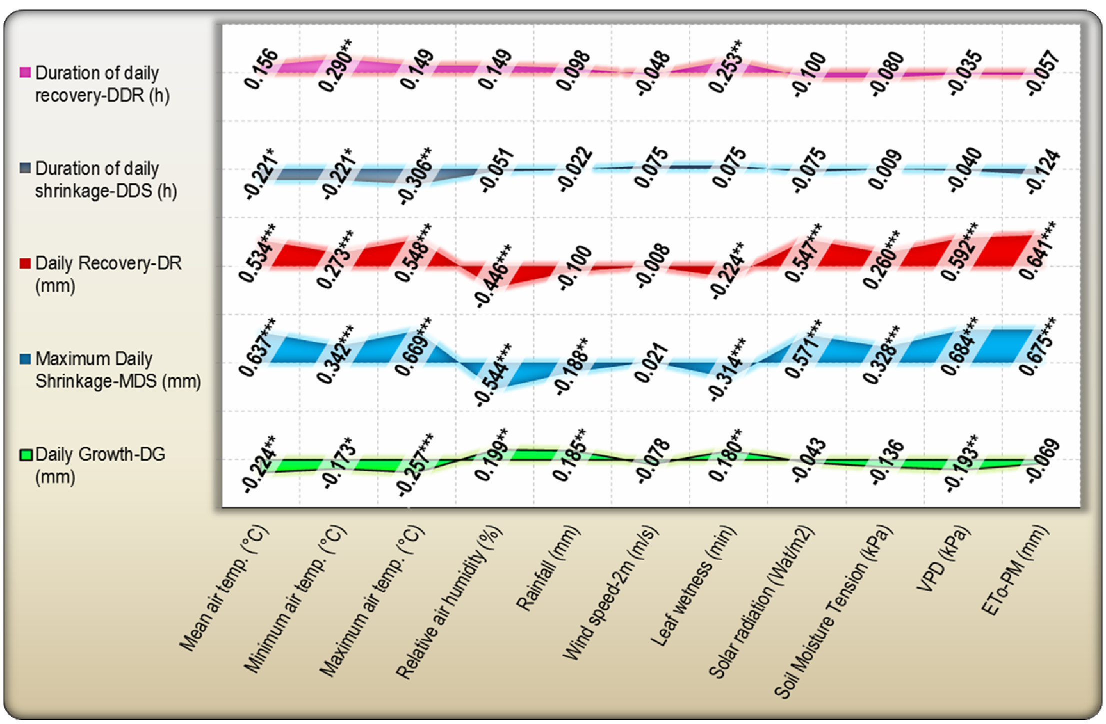


Fig. 25. The influence of the meteorological factors and soil moisture on the stem diameter variation derived indices (Pearson's correlations coefficients for Braeburn cv., 2011-2012 and May – September months)

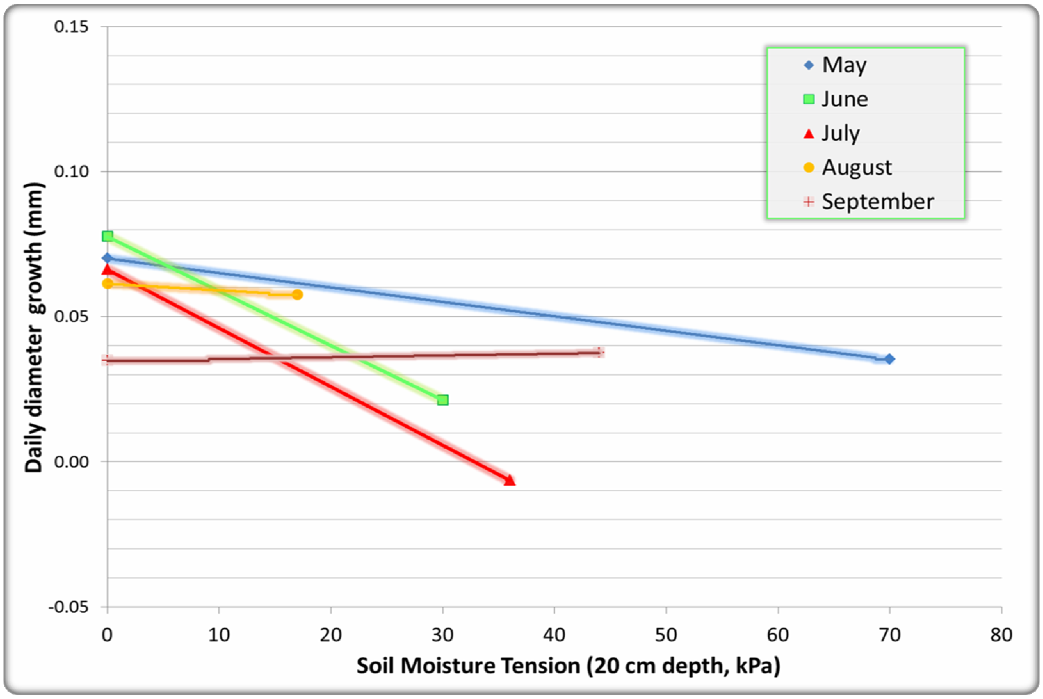


Fig. 26. Modeling the influence of SMT on DG, using multiple linear regression equations for each month of the growing season due for Redix cv. (2009-2011), using the experimental range of variation for SMT

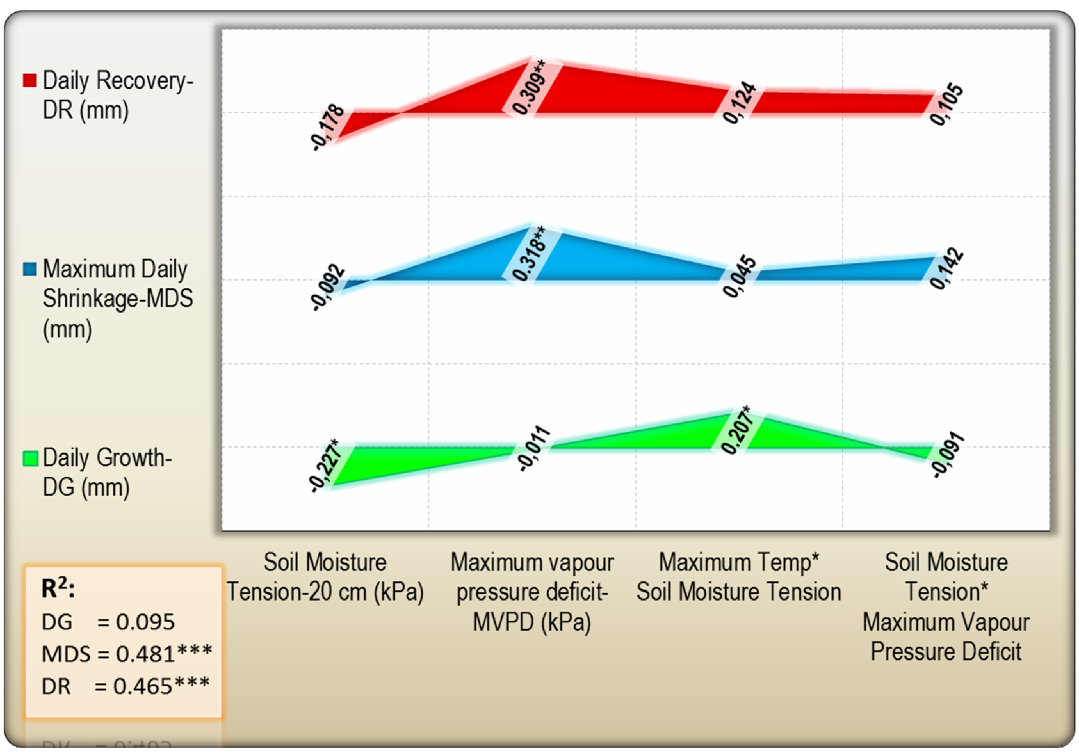


Fig. 27. The influence of the most strength meteorological factors and soil moisture on the stem diameter variation derived indices presented by partial correlations coefficients for Redix cv., 2009-2011 and May month

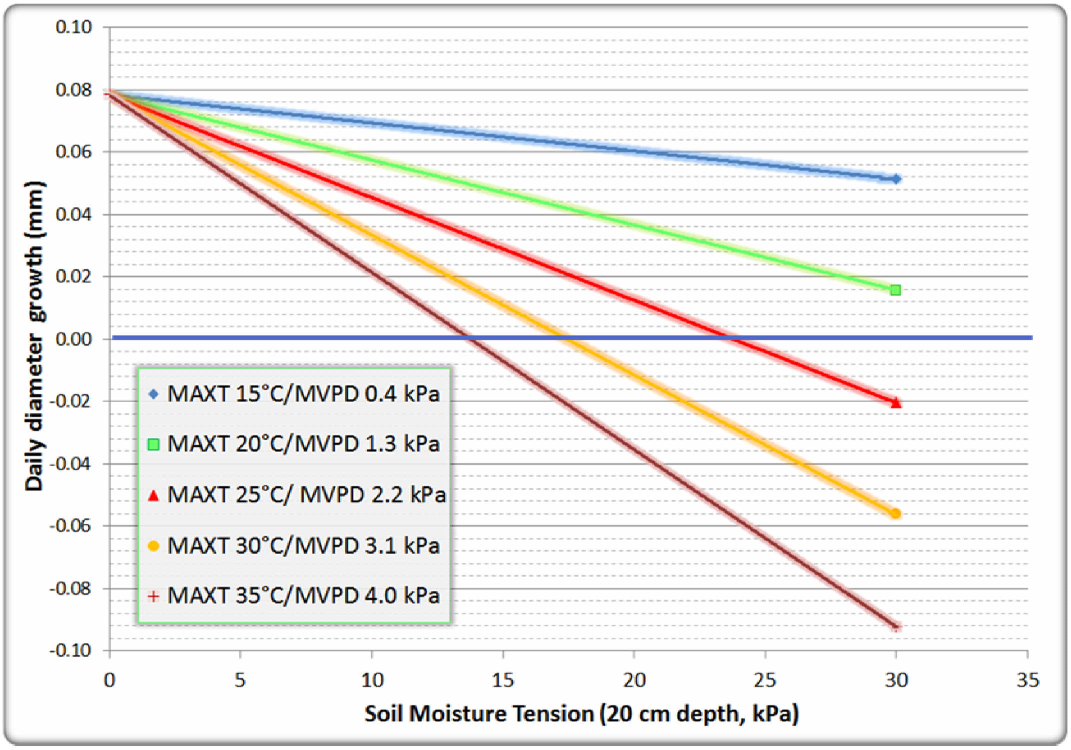


Fig. 28. Modeling of the influence of SMT on DG, using multiple linear regression equations with interactions for June and Redix cv. (2009-2011), using the experimental range of variation for SMT