A CLIMATE CHANGE CASE STUDY OF KESZTHELY USING CROP MICROCLIMATE SIMULATION MODEL

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Abstract

The results in the issue of local signs of global climate change at Keszthely are summarized and presented in this paper. The meteorological measurements at Keszthely have a long history and a more than 130-year-long dataset of monthly amount of precipitation and a more than 100-year-long dataset of homogenised monthly mean temperature that are available for statistical analysis at Keszthely Meteorological Station. The data set of precipitation is provided by the Department of Meteorology and Water Management of Georgikon Faculty at Keszthely and the time series of homogenised temperature data are provided by the Hungarian Meteorological Service. Simple climate-statistical analysis has been made in the purpose to discover local climate alternations.

Surprisingly, modifications were found neither in yearly amount of precipitation, nor in its variability according to linear trend analysis. It was proved that seasonal rainfall amount in spring decreased and between the monthly precipitations the precipitation amount declined in October. In the past century the yearly mean temperature and the seasonal average temperature of summer has significantly increased by 0.49°C and 0.61°C respectively, but the variability in seasonal mean temperatures of summer and fall seemed to decline.

According to the purpose of detecting local impacts of climate change researches were made about the microclimate of maize canopies and it can be concluded that in the energy transport of the plant stand no shift can be experienced to the direction of the latent heat as the effect of warming up and decrease of precipitation. From the changes of the stomatal resistance and of the inside canopy air temperature it can be concluded that the natural water supply will probably not cover the water demand of the plant, if the climate change is more intensive, therefore farmers must prepare to irrigate cultivation and to apply different agro-technical methods to save the water supplies of the ground if they want to achieve profitable production.

Key-words: climate change, Keszthely (Hungary), local modifications, temperature increase, precipitation decrease, microclimate simulation

Összefoglalás

Jelen publikációban a Keszthelyen, a klímaváltozás helyi megnyilvánulásai és hatásai témakörében folytatott kutatások eredményei kerülnek összefoglalásra. Keszthely meteorológiai mérései hosszú időszakra tekintenek vissza, így egy több mint 130 éves csapadék-adatsor a Pannon Egyetem Georgikon Kar Meteorológia és Vízgazdálkodás Tanszék jóvoltából, és egy több mint 100 éves homogenizált hőmérsék-

leti adatsor áll rendelkezésünkre statisztikai vizsgálatok céljára, amit az Országos Meteorológiai Szolgálat bocsátott rendelkezésre. A klímaváltozás helyi megnyilvánulásainak kimutatására egyszerű éghajlat-statisztikai paramétereket alkalmaztunk.

Megállapítható, hogy az éves csapadékadatokban nem mutatható ki lineáris változás, ugyanígy az adatok változékonyságában sem fedezhetünk fel statisztikailag igazolható módosulást. Az évszakos elemzések szerint tavasszal csökkenő tendencia jellemzi a csapadékösszegeket, valamint a hónapok közül Október esetében mutatható ki csapadékcsökkenés. Az éves középhőmérsékleti adatsor 0,49°C/100 év melegedést mutat, míg az évszakos hőmérsékleti adatokban a nyár esetén figyelhető meg felmelegedés (0,61°C/100 év). Az évszakos adatok változékonyságában nyáron és ősszel mutatható ki szignifikáns csökkenő tendencia.

Megvizsgáltuk a kukorica állományok mikroklímájában és fiziológiai folyamataiban a klímaváltozás hatására esetlegesen bekövetkező változásokat is. A kukorica állományok mikroklíma-vizsgálatai során megállapítható, hogy az állomány energiaforgalmában nem tapasztalható szignifikáns eltolódás a víz párologtatására szolgáló látens hő irányába a felmelegedés és csapadékcsökkenés hatására. A sztómaellenállás, a növény- és az állományon belüli légtér hőmérsékletének változásaiból arra következtethetünk, hogy a természetes vízellátás a klímaváltozás fokozódásával nem fogja fedezni a növényi vízigényt, így a kukorica gazdaságos termesztése érdekében a gazdáknak fel kell készülniük az öntözéses termesztésre, valamint a talaj vízkészleteinek megóvását segítő agrotechnikai eljárások alkalmazására.

Kulcsszavak: klímaváltozás, Keszthely (Magyarország), helyi módosulások, hőmérsékletemelkedés, csapadékcsökkenés, mikroklíma szimuláció

1. Introduction and aim of the research

Global climate change – according to recent researches – is a realistic risk for the human society; therefore preparation to the changes can not be avoided. Developing adaptation strategies involves many scientific fields such as climatology, economy and sociology. Numerous scientists of the world take part in the better understanding of this system with their researches of their own fields. Impacts of climate change differ not only between scientific fields, but it may have different effects and consequences on the different continents and geographical areas. In Europe's case, adaptation and possible mitigation is very important, because it's climate can be modified seriously in this century. The Carpathian Basin – in the heart of Europe – is one of the most vulnerable and the one of the less understood areas. In some cases the volume and the direction of the changes are not definite.

Changes in Hungary's climate have influence on all economical fields (e.g. health care, energy industry, tourism), but most of all on agriculture. The extreme temperature and precipitation changes of the last decade already had an effect on the life of our most valuable national treasure, Lake Balaton (the decrease of the water level as a consequence of the accumulated lack of precipitation). Data, which are suitable for the analysis of meteorological elements and examinations have been available at Keszthely for more than 130 years. Possessing these data, better conclusions can be drawn about the tendencies of weather changes and the phenomena in connection with the climate change.

First of all, the aim of our research was to analyse the data of the long term meteorological measurements at Keszthely from the point of view of climate-statistics. In the course of the analysis, possible evidences of the local signs of global climate change were searched. On the basis of the yearly, seasonal and monthly data the extent of the changes were determined, that have occurred in the values of the temperature and precipitation since the beginning of the observations. The detailed analysis of the history of meteorological measurements at Keszthely provided important background information to the determination of the weather changes (*Kocsis* and *Anda* 2004, *Kocsis* and *Bem* 2007).

Secondly, our attention turned to the acclimatization of the maize to a possible climate change. This crop has been growing at the experimental field for several decades, and some micrometeorological measurements were carried out in the crop canopy. At the Agrometeorological Research Station in Keszthely observations of the microclimate have been carried out for several decades and for one decade information was also gained by using simulation model about crop microclimate that could rarely be registered earlier. Using the earlier data of Keszthely station, and the downscaled information for the country and the watershed area of Lake Balaton, our aim was to simulate the adaptation of the microclimate and the physiological processes of the maize stand to some expected climatic conditions.

2. The materials and methods

2.1. Dataset and methods of the statistics

Monthly amounts of precipitation were measured and analysed from 1871 to 2000, at the beginning in the territory of the ancient Georgikon (Academy of Agriculture at Keszthely), then at the meteorological station of the Hungarian Meteorological Service. Later on the analysis was extended until 2006 and we also did additional linear trend analysis. The homogeneous dataset of the monthly mean temperature between 1901 and 2006 was made available by the Hungarian Meteorological Service that we used to calculate the seasonal and yearly mean temperatures. Seasonal means were calculated as used in meteorological practice: spring-March, April, May; summer-June, July, August; fall-September, October, November; winter-December, January, February. The temperature data was prepared by *Szentimrey* (2000) with a program called MASH (*Szalai* and *Szentimrey* 2001).

Trend analysis of time series from single point observations has often been used to define local climate trends (*Boyles* and *Raman* 2003). During the procession the data set was analysed by linear trend analysis and with running averages, which are widespread at the analysis of time series. The mean values, the dispersion and distribution attributes were also determined. The following ones from the simplest climatic and statistical attributes were applied (*Péczely* 1998): arithmetical average, the dimension of the data set, absolute divergence and dispersion. After putting the data in order we have determined the upper and lower quarter and the median. In the case of distribution, we calculated the amount of distortion and Köppen asymmetric index number.

Besides the simple statistic index numbers, further changes of the climate were examined with the following attributes. Climate modifications have two forms. In one case changeable weather appears in higher and lower values that follow each other but the fluctuation usually remains in an interval that is limited by the existing extremes. In this case we talk about climate fluctuation (*Varga-Haszonits* 2003). In the other case the interval of the fluctuation shifts to either direction: the fluctuation takes place in a significantly higher or significantly lower range. If this shift becomes constant for a longer time we speak about climate change. It is obvious that climate fluctuation can have two interpretations: one of them is the difference between the given value and the average of many years (in an absolute value), the other one is the difference between the values following each other (*Varga-Haszonits* 2003). In our examinations we used the first approach.

Most of the field crops is hit hard by a dry period that lasts more than 5-10 days and suffers irreversible damage (*Szász* 1994). In our examinations we analysed the dry periods from 1968 to 2006 in two time categories; one of them was 10-14 days and the other one was longer than 15 days (on the basis of daily data).

2.2. Crop Microclimate Simulation Model (CMSM)

The microclimate inside the plant canopy means the system of the characteristics of the air inside the canopy, (temperature, humidity, wind and other elements, which are in an interaction with each other). These are the direct environmental factors that determine the conditions of the plant production and it also has a direct effect on the organisms living together and this environmental condition has a direct effect on fungi, viruses and pests (*Hunkár* 1990).

The growth and productivity of wild and domestic plants are controlled by the metabolism and energy changes of the air that surround them. Metabolism includes the input of CO_2 and its utilization in photosynthesis and the circulation of water vapour (*Páll et al.* 1998). In order to simulate these processes we applied a microclimate simulation model, which was worked out by *Goudriaan* (1977). The model works on the basis of the description of the processes of energy changes inside the plant stand (*Páll et al.* 1998).

The basis of the simulation models is the numerical determination of the water balance, the light absorption and utilization of the leaves, the production of the dry matter and its division in the organs. *Goudriaan*'s (1977) simulation model and its improved version (*Goudriaan* and *Van Laar* 1994) follow the division of the radiation inside the canopy and its utilization in different energy-intensive processes (*Anda* and *Lőke* 2003).

The theoretical background of the Crop Micrometeorological Simulation Model (CMSM) is the physics of the energy-transfer and transport processes. The model calculates the characteristics of the microclimate and crop with the help of the law of the physics of the soil, the atmosphere and plant physiology (*Páll et al.*1998).

One part of the radiation energy that reaches the plants reflects, the second part penetrates into the stock and the third part is fixed by the plant stand (*Jones* 1983, *Anda* and *Lőke* 2003). This latter part is very important for the physiological processes because this is the starting point of the maintenance and operation of transpiration and photosynthesis. The two processes connected by the change of gases are inseparably linked by the stoma, which is responsible for both the transport of CO_2 and water vapour. While modelling both physiological processes the starting point is the fixed radiation energy of the canopy. The difference in the approach of the two physiological processes is the applied range of radiation spectra, which was taken into account, because when we determine the photosynthesis the fixing in the light is enough but at transpiration we must pay attention to the complete net radiation (*Anda* and *Lőke* 2003).

As the vertical structure of the plant stand is not homogeneous, the height of the plant is usually divided into a different number of layers, the characteristics of which can be regarded as more or less homogeneous (multi-layer model). The number of the layers can be influenced by the characteristics of the canopy, the aim and the element to be examined (*Goudriaan* 1977, *Anda et al.* 2002). In each layer there are energy sources and sinks. We must determine the intensity and the direction of the source and loss of the different forms of energy. The degree of the conversion of the energy, the direction and intensity of the flow all depend on the processes of the atmosphere, and the characteristics of the plants at a great extent, therefore the microclimate models regarding plant stands apply the connections of plant physiology as well (*Páll et al.* 1998).

On the basis of detailed calculations, the model creates profiles for the meteorological elements inside the canopy. The CMSM consists of three main parts: the sub-models of radiation, aerodynamics and soil. The first two models are static at all times according to the balance that exists in the atmosphere while the sub-model of the soil is dynamic.

Of the parameters calculated by the model we involved the sensible and latent heat fluxes, the air temperature inside the canopy, the plant temperature, the stomatal resistance, and the intensity of the photosynthesis into our simulation examinations. We described the sensible and latent heat fluxues in the form of their quotient, the Bowen-ratio (β).

We analysed the model results with a paired t-test in order to show the significant deviations. We did the calculations with the help of the STATA 5.0 (1996) statistical program package.

In order to simulate the effects of the global climate change on the maize stand we set up scenarios which shows the possible future weather conditions. We applied analogies for the crop architecture, the size and the density of the assimilating surface of the plant stand. We applied the plant characteristics as an input in the years the weather of which showed similarities to our scenarios. We raised the carbon dioxide concentration of the intercellular spaces in accordance with the changes of the carbon dioxide concentration of the atmosphere on the basis of the data of the literature (*Jackson et al.* 1994).

- Control: present climatic conditions (average day in July), average content of soil humidity (-7 bar ground water potential), CO_2 concentration of the air is 380 ppm. The value of LAI is 3.0, which is regarded as average at this time of year in Keszthely.
- Scenario 1: We reduced the soil humidity by 10% and rose the temperature of the air by 0.6ºC, (we supposed that the linear

changes continue on the basis of the meteorological data of July between 1977-2006 in Keszthely) and at the same time we reduced the LAI value to 2.8. The CO_2 concentration of the atmosphere was raised to 440 ppm (this concentration rise should be pared to 0.6 ºC temperature rise according to the explanation of János Mika).

- Scenario 2: The soil humidity was reduced by 25% and the temperature of the air was raised by 1.3ºC and at the same time the LAI value was reduced to 2.3. The CO_2 concentration of the atmosphere was raised to 760 ppm (doubled CO_2 concentration of the control run).
- Scenario 3: The soil humidity was reduced by 35% and the temperature of the air was raised by 2ºC and at the same time the LAI value was reduced to 2.0. The CO_2 concentration of the atmosphere was raised to 760 ppm.

3. Results

3.1. The analysis of the precipitation data series of Keszthely

In the course of the analysis of the data series (between 1871 and 2000) it can be concluded that in the case of the amount of precipitation a significant, linear decreasing tendency cannot be shown, and a modification in the variability of the annual data cannot be detected as well. However the distribution of the data indicates that in the examined period the majority of the years had a lower amount of precipitation. According to the Köppen distortion index the ratio of those years that have less precipitation amount than the average is higher in the data series. Both the series of the running averages and the climate normals (determined for 30 years following the WMO recommends) show that the amount of precipitation decreased in the second half of the 20^{th} century.

On the basis of the climate normals establishments, among the linear tendencies of the 30-year periods shifted by 10 years, the period between 1881 and 1910 shows a significant rise of precipitation. This was an interesting result, because significant decrease should have been expected for the late 20th century and not a rising tendency at the end of the 19th century.

Examining the data in each season, there is a statistically proved linear decrease of precipitation only in spring. The variability of the seasonal data does not alter significantly in either of the seasons (*Table 1.*). Regarding the yearly average of precipitation the secondary maximum in autumn seems to disappear. It is not completely clear that it would be the disappearance of secondary maximum or a shift in it, but according to the averages of 130-year-long data the monthly amounts of precipitation in the fall are nearly the same sum.

Table 1.

Changes in seasonal amount of precipitation at Keszthely (1871-2000)

**significant change in linear trend at 5% probability level*

Season	***Slope***	***R^2***
Spring	-0.3543	**0.0593***
Summer	-0.0541	0.0008
Fall	-0.2278	0.0157
Winter	0.1798	0.0253

The amount of precipitation in October shows a significant decrease between 1871 and 2000. The linear trend analysis extended until 2006 reinforce this statement.

During the examination of the number of periods without precipitation it can be concluded that farmers have to face at least one 15-day or two 10-14-day periods without precipitation in each growing season (*Kocsis* and *Anda* 2006a).

As a conclusion we can establish that the decrease of precipitation, which is regarded as one of the consequences of global climate change, can be observed as a seasonal phenomenon at Keszthely, however there are traces of the changes in the annual and monthly data. The decrease of precipitation in spring can have a critical effect on agricultural production because both the spring crop (germination) and the autumn crop (flowering) might suffer a fall of production because of rainless weather.

3.2. The analysis of the temperature data of Keszthely

In the data series of annual mean temperatures the warming up is significant (0.49ºC/100 years) between 1901 and 2000, but the temperature variability did not alter (*Kocsis* and *Anda* 2006b). The series of data extended until 2006 shows an even more intensive warming (0.58ºC/100 years). The fact of warming is reinforced by the changes of climate normals. On the basis of climate normals' method the linear tendency of the period between 1971 and 2000 shows significant warming (0.3ºC/10 years).

In summer a significant rise of the temperature (0.61ºC/100 years) appeared between 1901 and 2000 while in the other seasons we could not detect a statistically justified change (*Table 2.*).

Table 2.

Changes in seasonal mean temperatures at Keszthely (1901-2000)

**significant change in linear trend at 5% probability level*

Season	***Slope***	R^2
Spring	0.004	0.0112
Summer	0.0061	**0.0395***
Fall	0.0032	0.0066
Winter	0.0012	0.0009

The tendency of the data series extended until 2006 reinforces this statement, what is more, the rise in this case seems to be more intensive (0.8ºC/100 years). The changes of the summer and autumn mean temperatures decreased. The monthly data do not show a significant change.

It can be summarised that at Keszthely warming up, which can be proved statistically, is less intensive than the changes that was observed in other Transdanubian stations in the same period (1901-2000) by *Szalai* and *Szentimrey* (2001) who proved changes in yearly mean temperatures in Western Hungary between 0.72 and 0.85°C/100 years, and between 0.49 and 0.60°C/100 years in the part of Eastern Hungary. In summer the provable warming can influence tourism favourably, but it may also have an unfavourable effect on the water balance of the Lake Balaton and the water consumption of the plants because of the more intensive evaporation.

3.3. The examination of the effects of global climate change on maize by microclimate simulation model

The incoming radiation that is absorbed in a given crop layer after reflecting from the canopy or proceeding towards the soil, becomes the energy source of the heating processes (sensible heat flux), and evapotranspiration (latent heat flux). If there is no water restriction, evapotranspiration is the main energy consumer of the plant stand. We can get the Bowen ratio as the proportion of the sensible and latent heat fluxes. The statistical analysis shows that significant deviation cannot be observed from the control run in any of the scenarios.

The intensity of the photosynthesis and the transpiration are influenced by the concentration of CO_2 because of its effect on the stomatal resistance. In order to get a higher yield the plant must reach a balance between the possibly higher CO_2 amount that is needed for the photosynthesis, and gets into the leaves through the openings of the stomatas, and the level of the amount of water that leaves the foliage which must be as low as possible. The two opposing processes are connected by the pores.

The stomatas can be regarded as closed when the stomatal resistance surpasses 2000 s m-[1]. The stomatal resistance of the maize surpassed this value at night (between 8pm and 7am). On a daily average (between 8am and 7pm) the resistance rose by 16.76%, 61.55% and 69.1% in the 1st, 2nd, and 3rd scenarios, respectively comparing them to the control run (*Fig. 1.*). On the basis of statistical examinations these deviations indicate significant changes (*Anda* and *Kocsis* 2007).

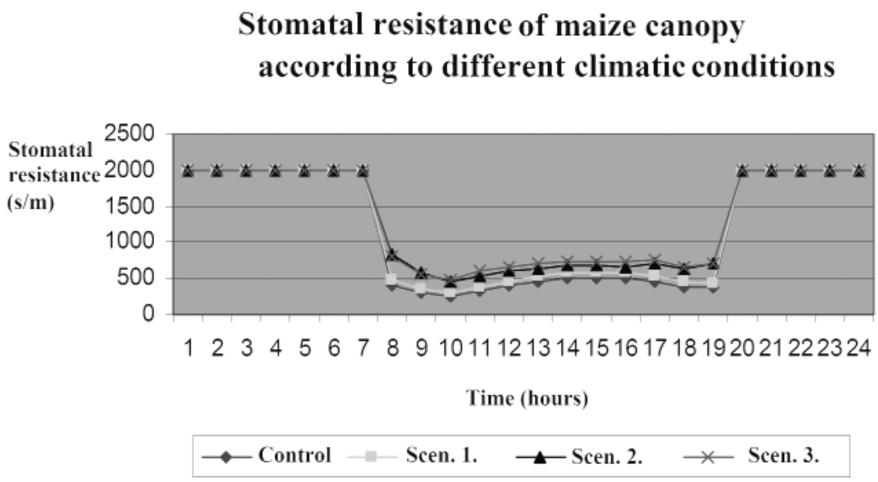

Fig. 1. Stomatal resistance of maize canopy according to different climatic conditions

In the course of the production of organic matter, the process of photosynthesis uses carbon dioxide from the surrounding air and water from the soil. The final benefit of the process is the difference between the amount of the organic matter created in the process of assimilation and used amount of assimilates in the course of respiration (at night). The intensity of the respiration (between 8pm and 6am) did not seem to be sensitive to the climate change. The intensity of the photosynthesis, in the average of the values of day time, slightly decreased in the 1st and 3rd scenarios, which indicates that the available carbon dioxide (440 ppm and 760 ppm) could not compensate the reduction of precipitation (that was represented by ground water potential decrease in the model runs) and although the water consumption became more economical because of the smaller stomatas, the amount of carbon dioxide that got into the foliage was also restricted. In the 2nd scenario the 760 ppm carbon dioxide concentration could compensate the effects of the restriction of precipitation, what is more the intensity of photosynthesis increased. While in the 1st and 2nd scenarios the change of the intensity of photosynthesis indicates a significant deviation comparing it to the control, the 3rd scenario does not show a significant deviation.

In the 2nd and 3rd scenario the 24-hour average value of the inside canopy air temperature surpassed the rise of the additional air temperature while the average rise in the 1st scenario was lower than the input temperature rise. The results of the plant temperature showed a higher rise in all the three scenarios than the rise of the ambient air temperature. In the case of the average values of the day time rise, the average growth in the crop temperature of all the three scenarios is lower than the added temperature rise. The reason for this phenomena can be the self-shade of plants by day, and the leaves gave a special protection against sunshine, therefore the inside canopy air temperature was more moderate than the temperature rise around it. In the case of the plant temperature the average rise is almost the same or a little lower than the input temperature rise. The plant could keep its own temperature close to the temperature of the air around it. Despite the decrease of the water supply and warming, the plant did not seem to suffer very much from the stress of the heat. The changes in all the three scenarios (regarding both temperature characteristics) show significant deviations.

From the changes of the stomatal resistance and temperature of the air inside the canopy, it can be concluded that the natural water supply will not cover the water demand of the plant with the manifestation of the climate change therefore farmers must prepare for irrigation and the application of agro-technical methods to save the water supplies of the ground in order to produce maize economically. However at the beginning of the climate change the maize plant at Keszthely is able to compensate the unfavourable conditions and does not suffer damage when the water supply is moderately less.

Discussion

The decrease of precipitation, which is regarded as one of the consequences of global warming cannot be detected in the annual data of Keszthely (according to linear regression between 1871 and 2000), but at a seasonal level it has an effect (spring). Modifications of the annual precipitation in the second part of the 20th century are shown by the detailed analysis. The decrease of the precipitation intake in spring can effect agricultural production badly. In the autumn months the secondary maximum seems to disappear. The precipitation amount in October shows a significant decrease. When examining the number of periods without precipitation it can be concluded that farmers have to face at least one 15-day long or two 10-14-day long precipitation free periods during one growing season.

At Keszthely it can be proved statistically that warming up (0.49°C/100 years) is lower than in the other stations in the Transdanubia (between 0.72 and 0.85°C/100 years according to *Szalai* and *Szen-*

timrey, 2001). This phenomenon may be in close connection with the presence of the Lake Balaton. It seems that the lake acts as a local compensator. On one hand in summer detected warming can have a favourable influence on tourism; on the other hand intensified transpiration can have an unfavourable influence on the changes of the water supply of Lake Balaton and the water consumption of the plants. A decrease can be detected in the variability of summer and autumn mean temperatures. We cannot detect a significant change in the monthly data.

Examining the microclimate of maize canopies it can be concluded that in the energy transport of the plant stand no shift can be experienced to the direction of the latent heat as the effect of warming up and the decrease of precipitation. The increase of the stomal resistance can be detected, while the intensity of the photosynthesis first increases, but when we assume stronger climate change, it decreases. Examining the changes of microclimatic elements, it can be concluded that besides the climate, the architecture of the plant stand has an important role as well. From the changes of the stomal resistance and of the inside canopy air temperature it can be concluded that the natural water supply will probably not cover the water demand of the plant, if the climate change is more intensive, therefore farmers must prepare to irrigated cultivation and to apply different agro-technical methods to save the water supplies of the ground if they want to achieve profitable production.

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EXPERIMENTS TO DETERMINE THE EVAPO-TRANSPIRATION OF REED STANDS

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Summary

The output side of the water balance of stagnant water bodies is basically determined by evapotranspiration. The experiments were carried out on studying the exact role of the common reed in the water management of stagnant water. During the observations we examined the water uptake of the common reed planted in evapotraspirometer growing chambers as a function of potential evapotranspiration. As a result of the study, we managed to determine the crop coefficient values characteristic of two seasons of a reed stand that had been developing under constant water cover. Our experiments confirmed the earlier findings, that in some cases the reed stand may transpire more water than that of the open water bodies. The possible reasons might have been the special growing environment of reed. This crop is standing in the water, where there is no water limitation. The canopy evapotranspiration contains two separate parts, the first is the potential evapotranspiration of the lake water below the crop, and the second is the transpiration of reed itself at unlimited watering level.

Keywords: evapotranspiration, reed, crop coefficient, leaf area index (LAI), oasis effect,

Összefoglalás

Napjainkban nagy feladatot jelent a kutatók számára tavaink vízháztartási mérlegének vizsgálata során a párolgás és párologtatás számítása és mérése. A vízfelszínről elpárolgó, és a növényzet által elpárologtatott víz mennyisége és aránya a vízmérleg kiadási oldalát döntően meghatározza.

A növényállományok párolgása elsősorban a mocsaras területek, valamint a partmenti növényborítással rendelkező vizeink vízháztartását határozhatja meg. Ez jellemző a Balatonra, mivel a tó partvonalának jelentős részét összefüggő nádas borítja.

Vizsgálatunk célkitűzése a Kis-Balaton és a Balaton vízparti növényállományaiban meghatározó szerepű nád párologtatásának megfigyelése. A párolgás napi gyakorisággal történő folyamatos követése alapján annak nagyságát a szabad vízfelszín evaporációjához viszonyítjuk. A növényállomány evapotranspirációjának tenyészidőszakon belüli változásai és az időjárás valamint a növényállományok szerkezetének változása közötti kapcsolatot megpróbáltuk feltárni.

Munkám során evapotranspirométerekbe telepített közönséges nád vízfelvételét vizsgáltam a potenciális evapotranspiráció függvényében. A kutatás eredményeként két évjáratban vízborításos körül-

mények között fejlődött állományban sikerült megállapítanunk a nádra vonatkozó növény-konstans értékeket.

Vizsgálataimból kiderült, hogy a nádállomány a megszokottnál sokkal több vizet párologtat. A növénykonstans számunkra ismeretlen okból egyes napokon kimagasló 4-től 8-as értéket is elérhet. A magas növénykonstans értékek egyik oka az úgynevezett oázis hatás lehet, vagyis a tenyészedényt körülvevő szárazabb élőhely advekciója, a másik ok a tenyészedényben kialakult rizóma-talaj rendszer vízkapacitásában keresendő.

Introduction

Nowadays it is a major task for researchers and specialists to analyse the water management of our lakes, to calculate and to measure the evaporation and transpiration. The output side of the lake water balance is basically determined by the plant transpiration and surface evaporation. Reed transpiration determinations in Hungary go back to several decades: observations were focused on Fertő Lake (Hungary) in the 1970's (*Walkovszky* 1973; 1974). Near Hungary, abroad reed transpiration measurements were taken by using lysimeters in the Danube delta (Ondok et al. 1998; Rodewald-Rudescu 1974 in Austria at Fertő Lake (Tuschl 1970); in Polandat the Mazuri Lakes (Bernatowicz et al. 1976); in fishponds at Czechoslovakia (Smid 1975), respectively.

The transpiration of plant canopies mainly determines the water management of wetlands, and that of the water bodies with coastal plant coverage, which is typical of Lake Balaton, the coastline of which is covered by continuous strips of reed.

Ondok et al. (1998) studied the evapotranspiration of wetland plants to see how much the vegetation increases or decreases the evaporation compared to that of the open water surface. The E_t/E_w proportion, ($E_{t:}$ evapotranspiration of the plants; E_w: the evaporation of the water surface) was used to compare the different wetland crops.

The E_t/E_w proportion, that is the crop coefficient, is used to describe differences between the water loss of the plant canopies and that of the open water surface. The basis of comparison is the potential evapotranspiration, the maximum water vapour receiving capacity of the air measured at non limited water supply. This is the case in water bodies, or lakes.

The aim of our study was to observe the transpiration of the common reed, a determinant of the plant stands of Lake Balaton and the so called Little Balaton (Kis-Balaton) area. The rate of actual evapotranspiration measured on a daily basis was compared to that of the open water surface one (potential evapotranspiration).We tried to explore the correlation that may exist between the structural changes of a plant stand and the fluctuation of its water loss during the vegetation period.

Material and methods

Investigations were carried out at the Agrometeorology Research Station settled to the area of the Pannon University at Keszthely, during the consecutive growing seasons of 2008 and 2009.

To measure the actual evapotranspiration Thornthwaite-Mather-type compensation evapotranspirometers were applied (Fig. 1). The basis of water loss measurement was the following of water balance components, and expressing the crop evapotranspiration as a residual member of the balance. The surface size of the growing chambers (tanks) was 4 m^2 with the depth of them was 1 m. One tank contained 4 m^3 soil characteristic to the surrounding land (Ramann type brown forest soil). The number of replications was four.

The common reed (*Phragmites communis)* was planted in April 2003. The crop samples were taken locally from the strip surrounding the lake. In the next two years the evapotraspirometers went on working properly on the basic principle of communicating vessels, although the plant development was not undisturbed. The average height of reed grown in the closed growing chambers did not reach the plant height of those ones measured in the Balaton's lakeshore. By 2006, the reed stand developed a rhizome system dense enough too block the soil tanks and stop the connection with the compensation reservoir tank. Later on, we separated the tanks from the expansion tank and topped them up with water. The daily water loss was determined on a mm scale in separated part of the 4 m^2 tank surface (Fig. 2), and the water was also topped up from above. The tanks had 5-10 cm of water cover, depending on the crop development. The actual water level can be read in mm scale. Continuous calibration has been properly made only since 2008; unfortunately, the data of 2007 were unreliable.

Fig. 1 The tank (growing chamber) of the evapotranspirometer with the reed stand

Fig. 2 The measurement point in the corner of the converted tank

Measurements were taken at 7 a.m. every day from the beginning of April till the end of September. Calibration was repeated in accordance with the change of the vegetation development on a monthly basis. Weather data observation was taken on the premises with an QLC-50 type automatic climate station.

To define the potential evapotranspiration (PET) we used the *Antal*'s (1962) empiric formula as follows:

$$PET = 0{,}9\left[E - e\right]^{0,7}\left(1 + \alpha T\right)^{4,8} \qquad (1)$$

where E: the saturation vapour pressure belonging to the daily mean temperature (mbar)

e: the daily average vapour pressure (mbar)

α: the air's expansion coefficient (1/273K^{-1})

T: the daily mean temperature (^{o}C).

The plant stand was characterised with the number of plants /m^2; the average height of the plant stand; and one of the most important characteristic features from the point of view of transpiration, the leaf area index (LAI). It means the assimilatory or transpiring surface as well. The LAI values were determined weekly.

The k_c, the crop coefficient was the ratio of measured (ET) and potential (PET) evapotranspirations:

$$k_c = \frac{ET}{PET} \qquad (2)$$

The crop coefficint values were calculated on a daily basis.

Results

The crop properties

2008 had a mild winter poor in precipitation and the reeds started to emerge on March 20th. The spring was as usual, April was warmer, and not very wet. June was warm and wet, July and August were as usual. The maximum leaf area index of 3.53 was reached by the second week of July, at the same time with the blossoming, with 120 sprouts per/m^2 (Fig. 3). The average height of the measured stand was 253 cm, the highest plant reached the 297 cm.

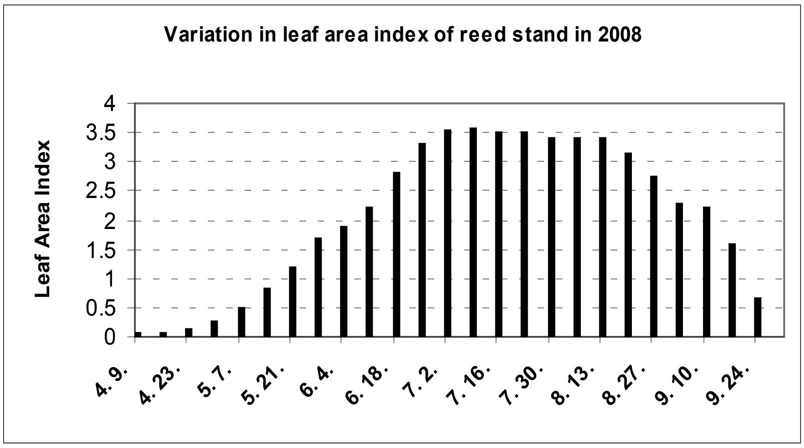

Fig. 3 Weekly LAI of the reed stand in the vegetation period of 2008

In 2009, after the cold and wet winter, the first reed sprouts emerged on March 25th. The spring was as usual, with a warm and rainless April. June was as usual, July and August were warmer and drier than the average climate normal. The maximum leaf area index (3.86) was reached by the second week of July, at the same time with the blossoming, with 125 sprouts per/m^2 (Fig. 4). The average height of the measured stand was 258 cm, the highest plant 297 cm.

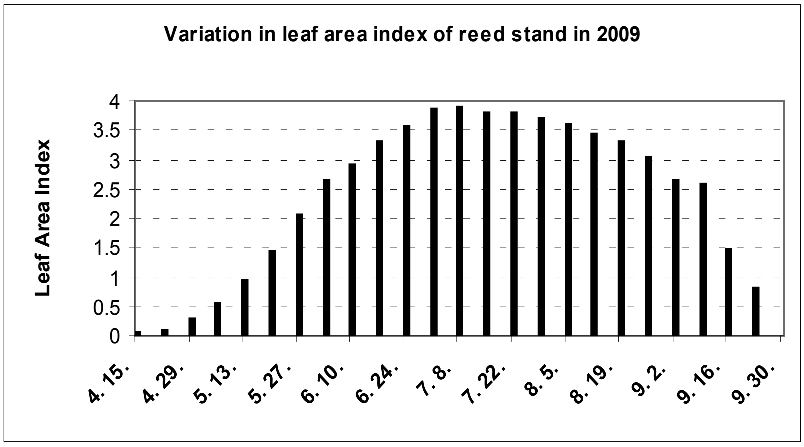

Fig. 4 Weekly change in LAI of the reed stand in the vegetation period of 2009

The changes of the evapotranspiation of the reed stand during the observations

In 2008, during the vegetation period, and mainly in the blossoming period, the reed evapotranspiration values sometimes greatly exceeded the potential evapotranspiration ones (Fig. 5). On certain days, the crop coefficient was outstandingly high, reaching the values of 4 to 8. The monthly average was the highest in June, during the period of intensive growth (Table 1).

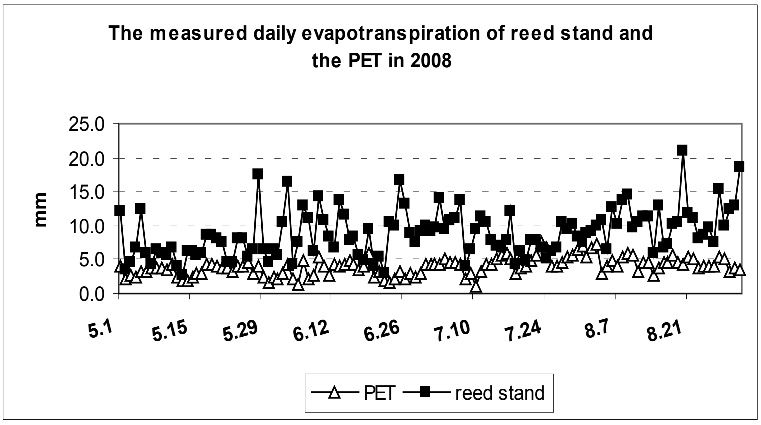

Fig. 5 Daily transpiration and PET of the reed stand in 2008

Month/Year	**2008**	**2009**
May	2.1	2.1
June	3.0	2.6
July	2.1	2.4
August	2.5	2.2

Table 1. Monthly crop coefficient values for reed grown in lysimeters

We tried to find correlation between the weather elements and reed water loss, however we only managed a mean correlation between the five-day temperature sum and the five-day evaporation sum, that was R=0.54.

In June 2009, the monthly average crop coefficient reached extremely high values. We experienced fewer outstanding daily values in 2009 than in 2008. The correlation coefficient between the five-day heat sums and the five-day evaporation amounts was 0.78, higher than that of the coefficient in the previous season.

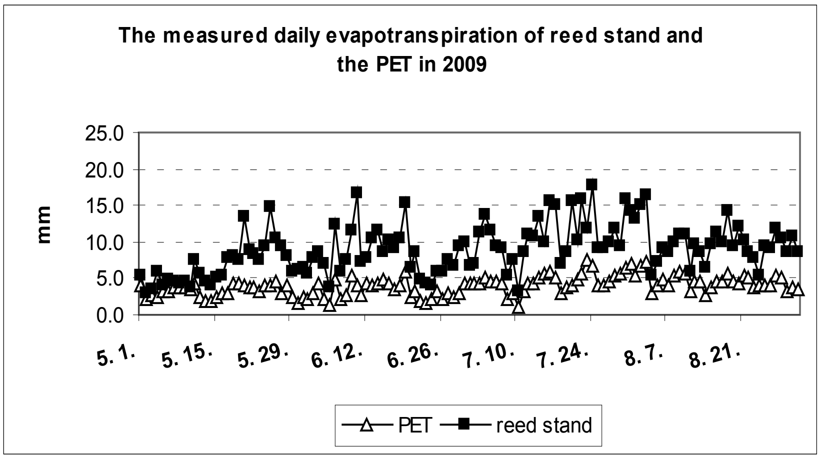

Fig. 6 Daily evapotranspiration sums and the PET in 2009

Conclusions

Our experiments confirmed the earlier findings, that in some cases the reed stand may transpire more water than that of the open water bodies. The possible reasons might have been the special growing environment of reed. This crop is standing in the water, where there is no water limitation. The canopy evapotranspiration contains two separate parts, the first is the potential evapotranspiration of the lake water below the crop, and the second is the transpiration of reed itself at unlimited watering level.

We should mentioned that on certain days the crop coefficient – for unknown reasons – reached outstanding values ranging between 4 and 8. One reason could be the so called plant oasis effect, that is the result of advection coming from the drier habitat surrounding the tanks. The other might be the water retaining capacity of the soil fulfilled with rhizome. This outcome needs further and deeper investigations to improve the accuracy of our results.

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NEW TECHNIQUES OF MONITORING THE PROCESS OF WATER TRANSPORT IN LIVE PLANTS

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Abstract

The purposes of our study have been to extend to plant-water relations the potential applications of MRI (applied in human diagnostics), and to verify the previous knowledge. A species of ligneous-stem privet (Phylleria angustifolia) has been selected for test plant. The measurements have been carried out at the Diagnostics and Oncoradiological Institute of the Kaposvár University (Hungary), using a MR apparatus Type Avanto of Siemens. The analyses have proved that the actual water content in each point of the stem may be modified by stem bifurcations and tissue formations. The presence of water barriers by nodes has been verified by the analysis of the signal intensities of the vegetable stem. Non-destructive "*in vivo*" MR methodology may have considerable functions in getting information, more important than the former ones, about the water transport processes between the plant and the soil and within the plant. This procedure may serve research and education with a high degree of probability.

Key words: MRI, water transport, signal intensity

Összefoglalás

A vizsgálatunk célja a humándiagnosztikában alkalmazott MRI alkalmazási lehetőségének növény-víz kapcsolatra történő kiterjesztése, valamint a korábbi ismeretek igazolása volt. Tesztnövénynek a fás szárú olajfagyalt (Phylleria angustifolia) választottuk. A méréseket a Kaposvári Egyetem Diagnosztikai és Onkoradiológiai Intézetében, egy Siemens Avanto típusú MR készülék alkalmazásával végeztük. Az elemzés során beigazolódott, hogy a szár egyes pontjainak aktuális víztartalmát az elágazások, valamint a szöveti képződmények módosíthatják. A növényi szár jelintenzitás vizsgálata megerősítette a nóduszok alkotta vízgátak meglétét. A nem destruktív, *„in-vivo”* MR módszertanra jelentős szerep várhat a növény és a talaj közötti, valamint a növényen belüli víztranszport folyamatok korábbiaknál pontosabb megismerésében. Az eljárás nagy valószínűséggel a kutatást és az oktatást is szolgálhatja.

Introduction

The expectable impacts of global warming (IPCC 2007), changes in the precipitation appear to be one of the most probable consequences of climate change in Hungary – almost regardless of the length of forecast intervals. The prediction of this component has a fairly high uncertainty, and the sign proper is affected by warming – a low warming may be associated with declining annual precipitations, whereas an increase of the annual mean temperature by over 3 to 4°C may produce expectedly ampler annual precipitations (*Bartholy et al.* 2009, *Szépszó and Horányi* 2008, *Mika* 2008). However, plants may be endangered not only by changes in the quantity of precipitation, but – at least to the same extent – by the temporal distribution thereof, compared with the appearance of rains different from the usual annual water intake (*Anda* 2004). Those inevitable negative omens may draw our attention to the importance of getting information (more accurate than before) about the plant-water relation, by the use of new devices available as a result of advancing technology. Such a technique may be the application of MR method (usual in human diagnostic so far) in getting information about the water transport of plants. This procedure represents an entirely new approach in the study of plant-water relation, by which our former knowledge may be evidenced or even enriched by new ones.

An everyday problem in the classical measurements of the components of vegetable water metabolism is the way in which a component of the plant – as the "random taken" component of the soil-plant-atmosphere system – will respond to interventions by the study and, the parameter to be measured is affected, and to what extent, by the measurement procedure itself. An example should be the measurement of stoma resistance (a method widely accepted in the determination of transpiration); in this procedure, all components of the micro-environment will be modified immediately by clamping the leaf in the probe of porometer. Knowing the short response times of stomas, the degree of openness of the pores will be changed as well (*Anda* 2001). Another basic problem of measurements applied in studying classical plant-water relations is their destructive nature; the opportunity of repeating the measurement is entirely eliminated for a given test specimen. Of the deficiencies of traditional approaches, MRI is capable of eliminating the second potential error – it is a non-destructive method, thus a particular sample of live and functional plant can be tested even several times in succession.

Studies of plant physiological aspects often involve an inaccuracy of measuring the components of vegetable water metabolism (*Pearcy et al.* 1991). The duty of researchers is made fairly difficult by the sensitivity of living organisms responding immediately to any minor or major changes, external or internal ones. The sensitivity of a plant often manifests itself in the broad scattering of the parameter being measured; this may often be due to the measurement itself – covering the actual relations as well as the comparisons. MRI appears to be an extremely efficient means of eliminating that potential error. The procedure involves a measurement of spin systems in the live plant; it will not intervene harshly into the system under test. The spins only have weak interactions with macroscopic parameters of the biological system under test, that will affect its behaviour from biological and chemical aspects. Magnetic properties play a fairly irrelevant role in biochemical processes at levels of cells (*Berényi et al.* 1997). On the other hand, biochemical parameters will affect the behaviour of spin systems in a readily measurable manner – i.e. conclusions may be drawn from measurements of spin systems on behaviour of the biological system under test (*Berényi et al.* 1997, *Földes et al.* 2003).

A few decades ago the plant-water relations were studied primarily in their components, as fractional processes. They are the water absorption of the root, its transmission to the evaporating surface, and the transpiration through the leaf. This subject has a literature too broad to be listed (*Ketelapper* 1963, *Kanemasu* 1969, *Lange et al.* 1976, *Lange et al.* 1976, *Jarvis and Mansfield* 1981, *Monteith 1*973, 1976, *Monteith et al.* 1990 etc.) – occasionally discussing in detail the potential errors of measurement (*Johnson* 1981, *Norman et al.* 1981, *Meyer et al.* 1985, *McDermitt* 1990 etc.). It must have been the error of measurement that led to the need of studying the complex behaviour of the soil – plant – atmosphere system. That need may not be referred to as having been focused recently (*Shawcroft et al.* 1974, *Norman* 1979, *Goudriaan and van Laar* 1974, *Bouman et al. 1996*) – although its real renaissance coincides with the energetic-based approaches, the spreading of models. Spreading of the systems outlook has given rise to the need of viewing the living beings in conjunction with their environments, holding in mind all possible negative consequences of removing them from the environment (*Brisson et al.* 2003, *Pronk et al.* 2007). Although the importance of systems outlook is recognized, most of the analyses of plant – water relations focus on two end points of the system even today – on water intake from the soil (e.g. *Jackson et al.* 2000, *Novak et al.* 2005) or delivery of water, transpiration (e.g. *Langensiepen et al.* 2009). The transport of water inside the plant, the changes occurring in the stem are reviewed less frequently. This may be due to the fact that, since the exact determination of transport of water inside the plant – definition of water potential – it is a familiar fact that such a process requires no extra energy input by the plant; the process is maintained by the water potential difference between the soil and the atmosphere (*Sutcliffe* 1984). Our analysis has focused again on the transport of water in the shoot; its timeliness is due to the potentials of MRI, the novel procedure applied hardly in the plant - water relation so far.

The first human MR record was made by *Damadian et al.* (1977) in 1977. Since that time MR has become one of the first leading imaging diagnostics in medicine. Having spread in human diagnostics, MRI was soon put to use in the studies of plants. Today MRI and NMR are used most commonly in modelling the ripening processes of fruits (*Raffo et al.* 2005; *Musse et al.* 2009). Due to its resolution, MRI is outstanding in determining the structural components of fungi as well as plants (*Musse et al.* 2009). Explicit examples of detecting water transport processes in the plant are provided by *Schaafsma et al.* (1992) and *Scheenen et al.* (2002).

Material and Methods

The external magnetic field, the electromagnetic waves and the interactions between the hydrogen atoms of matter provide the basis of MRI examination. Accordingly, MR will measure the quantity and distribution of protons. Of materials, water contains protons by far in a relative majority; thus it is highly suitable for the determination of plant water relations. MRI will measure the quantity and distribution of water in the given anatomic structure, not the anatomic structure concerned**;** it will, determine the anatomic unit in question. Application of MR will enable the study of the quantity and distribution (or even the tissue structure) of the crop sample.

The site of studies was the Diagnostics and Oncoradiological Institute of the Kaposvár University (Hungary). The studies were carried out by using a Siemens MR apparatus Type Avanto capable of generating a magnetic field of 1.5 T. The repetition and echo times applied in the measurements were 5.27 and 2.38 s, respectively. The study made by us involved a pixel spacing of 0.78 mm and a slice thickness of 0.7 mm; accordingly the resolution referred to a pixel slab/block was 0.43 mm^3. this means that a signal intensity value is obtained from a plant volume equivalent to that slab, plotted versus the distance above the soil (mm) on the main shoot, and versus the distance from the main shoot (mm) in the side branches.

A ligneous-stem species of privet (*Phyllirea angustifolia*) was selected for test plant. The privet under test produced a main branch, thick side branches that had three additional shoots. The analyses were carried out separately at each level of branching. The side branches and main shoot of the plant were numbered, to which reference will be made subsequently on the basis of Figure 1. The plants were 2-year old, 30 to 35 cm high, grown in pots. The peat/turf was saturated up to full water capacity during the measurements. Records/photos were taken in six repetitions at each sequence of the privet plant. The sequence applied by us is a human diagnostic mix, the basis of which was provided by sequences developed for the examination of skull, ankle and knee. Owing to the small size of privet relative to the human body, a cranial – thoracic (body) roll was used with a view to an adequate visibility. The cranial and the thoracic rolls ensured the sights of the plant and the root, respectively.

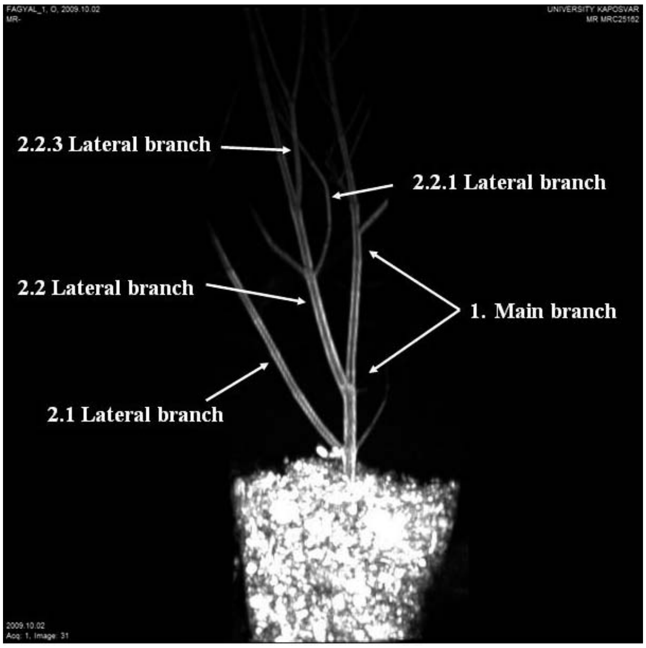

Figure 1 – Marking the lateral branches and main branch (shoot) of privet. The number of digits in the marking is inversely proportional to the level (order) of the shoot

The findings have been evaluated by the application of correlation calculations and regression analysis in studying the relation between the signal intensity and humidity content in the stem. Being a non-normal distribution involved, the distribution of data has been examined by the chi^2 test. Both analyses have been carried out by the use of software package Stata 5.0.

Results of Findings

Findings in the Main Shoot

MRI also provides the possibility of obtaining two data from a particular slice of the vegetable stem (hereinafter referred to as values on the right and left sides). The independence of the signal intensities measured on two sides of the stem were certified by the chi square test, because the frequency distribution was a non-normal one. The calculated figure is 26694.43, the one in the table is 27.58 (n=17), thus the signal intensities on the two sides (water contents) are in fact not independent of each other. There is a very close correlation between the signal intensities of the two sides (r=0.9025), although they exhibit a slight difference.

The water content in the plant is not independent of its height (Figure 2) where, in agreement with out previous knowledge, the higher values are exhibited along the section close to the soil. Our detailed analyses have exhibited periodic variations in water contents with the height of stem. There is a more marked difference between the nodes and the internodal points; it may be attributed to the specific structure of the node. The potter beams of the node grow in a nearly horizontal pattern, not parallel to the axis of shooting (*Haraszty* 1978) with different tissue structures (less sclerenchimas, more collenchimas) associated with the difference of humidity contents between the node and the internodium – in fact a water barrier emerges. The periodic emergence of barriers is illustrated by the curve of the signal intensities on the right side (Figure 3). Figure 4 can follow the decline of water flow from the soil to the top level of the height of main shoot with reference to varying intensities of nodes. A straight line can be fitted over the signal intensities of nodes in the main shoot (y= -0.23 x + 79.69; R^2=0.8138).

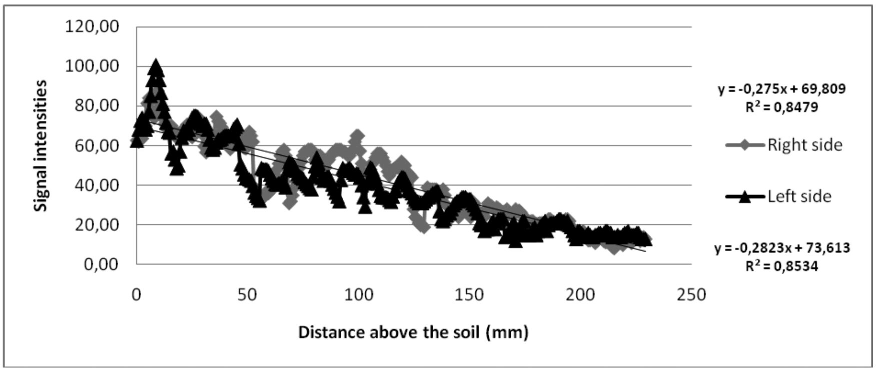

Figure 2 – Signal intensities at two sides of the main shoot, plotted versus distance above the soil. The two sides are referred to as right and left sides in the text

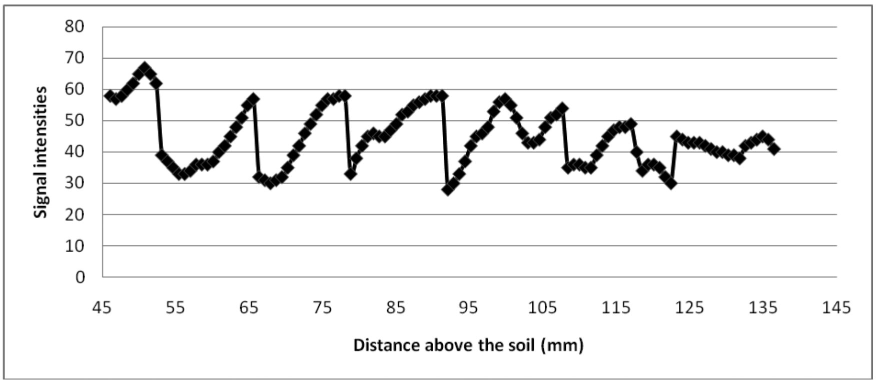

Figure 3 – Signal intensities at the nodes and internodia on the right side of main shoot

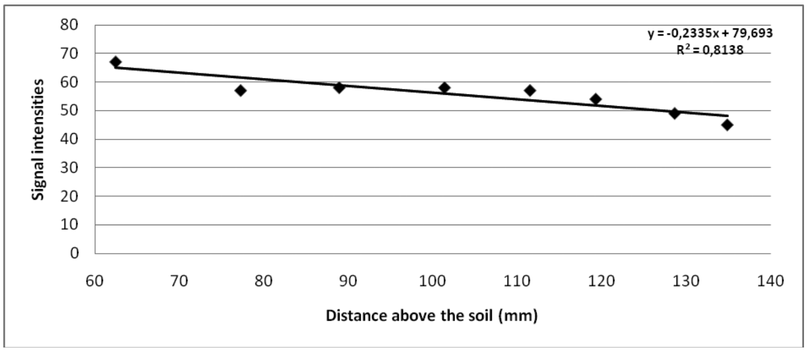

Figure 4 – Variations in signal intensities at the right-hand nodes of the main shoot, plotted versus soil distance

The dependence of signal intensity – plant height on each side can be approximated by a linear line exhibiting a linearity of 71.86% - i.e. 83 of the 295 data pairs are "irregular" ones. Sections of intensity, visible even by the naked eye, can be distinguished within the height of plant; yet this distinction has been accomplished by a mathematical-statistical procedure not in a subjective manner. The sections have been made with data featuring standard errors below 2% being grouped into a common category. Thus, as a result, five linear graphs have been obtained on each of the right and left sides of the plant stem.

Lateral Shoot Studies

Table 1 shows the slopes of linear curve fitted over the signal intensities of the main and lateral branches, separately for the parts of branch on the right and left sides. Each slope has a negative sign indicating the decrease of water content with increasing distance from he soil and the main branch. The correlation coefficient refers to the close correlation between the right and left sides as regards the branch as a whole (the main shoot and each of the lateral shoots). This should be emphasized because that correlation is not predominant always in the separated sections of the shoots, varying with their anatomic structures. The difference is due to the numbers of leaves and branches varying with the particular sides. The traditional studies involved difficulties in analysing the water movements in such details, or failed to enable such analysis at all. An example of this is the "parting" of signal intensities at the right and left sides of section 35 to 75 mm in Figure 5; this is accompanied by the separate different slopes of the fractional straight lines pertaining to the above section. In the case of lateral shoot 2.1 the difference may be due to the difference in the number of leaves on the two sides (Figure 6). There are 7 and 4 leaves on the right and left sides of the lateral shoot, respectively. This fact accounts for the higher signal intensity of the right-hand shoot and, hence its higher humidity content. Our studies have confirmed that the more leaves or branchings are located on a shoot, the higher will be its water content in that particular shoot segment.

Table 1 –
Equations of straight lines fitted over shoots of different orders (classes)

Number of shoot	Part of shoot	Equation of the straight line	Precipitousness of equation	Coefficient of corellation
1	Right	y=-0.28x+73.61	-0.28	0.9025
	Left	y=-0.28x+69.8	-0.28	
2.1	Right	y=-0.15x+44.70	-0.15	0.6961
	Left	y=-0.27x+57.73	-0.27	
2.2	Right	y=-0.30x+63.92	-0.30	0.932
	Left	y=-0.27x+59.74	-0.27	
2.2.1	Complete shoot	y=-0.10x+29	-0.10	
2.2.3	Right	y=-0.05+30.46	-0.05	0.3634
	Left	y=-0.08x+37.35	-0.08	

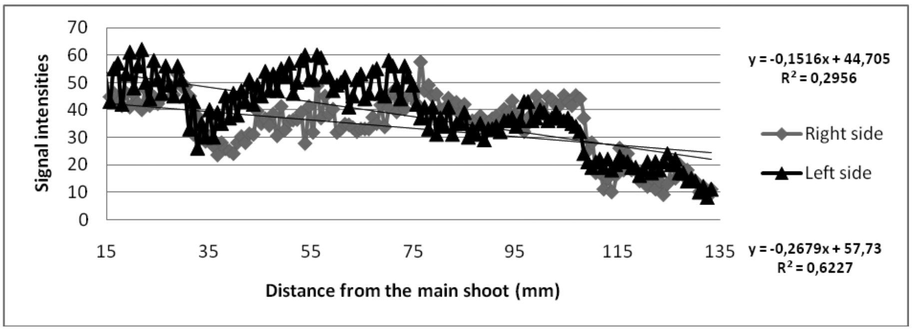

Figure 5 – Intensities of signals measured at two sides of a lateral shoot (2.1) plotted versus distance from the main shoot

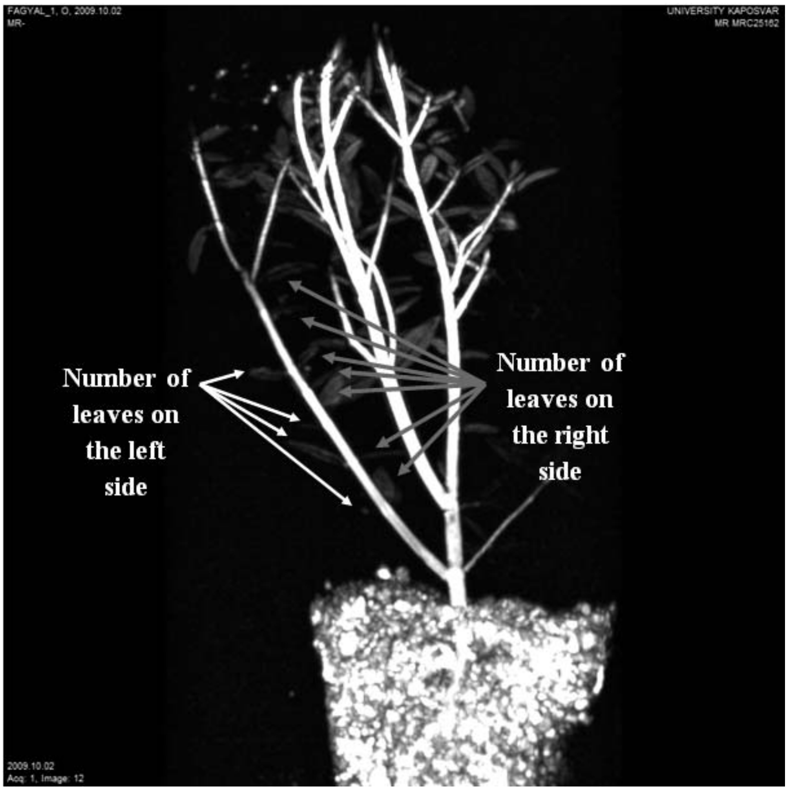

Figure 6 –
Location of leaves with reference to record T_1 of the sample plants

In the case of privet (Phylleria angustifolia), the branchings from the lateral branches may reduce the diameter of stem to such an extent that the difference of signal intensities disappears entirely between the differences of signals at the right and left sides (see the result of shoot 2.2.1 in Table 1). The dependence of vegetable development (thickness of stem) of the above relation is exemplified by shoot 2.2.3; it is of the same order as inseparable shoot 2.2.1 but exhibits a difference of 139.5% in terms of thickness.

Characteristic Features of Signal Intensities of Nodes

It has been established previously that the special formations on the stem of plant (nodes) represent a water barrier in the path of transpiration water flow. The water contents in those morphological units differ from those of internodia. The variability of water content produces the specific "serrated" curve of signal intensity (Figures 2, 5). This phenomenon is independent of the order (class) of shoot.

The direction of change in the signal intensity at the nodes coincides with the distribution of water content in the plant as a whole (Figure 7). A linear relation could be found in the signal intensities of nodes similar to the full shoot, beginning from the soil and/or the branchings (Table 2).

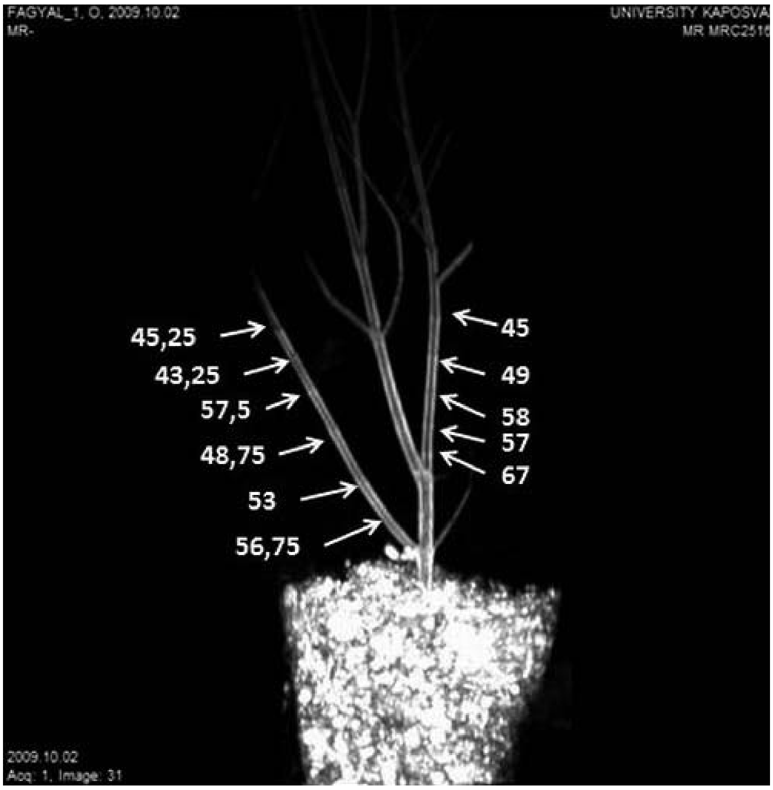

Figure 7 – Variations of signal intensities at the nodes, plotted versus distance, on the main shoot and lateral shoot 2.1

Table 2 – Equations of straight lines fitted over the signal intensities of nodes

Number of shoot nodes	Equation of the straight line	Precipitousness of equation	Coefficient of corellation
1	y=-0.23x+79.69	-0.23	-0.902132694
2.1	y=-0.25x+63.15	-0.25	-0.786624036
2.2	y=-0.25x+59.74	-0.25	-0.962186361
2.2.1	y=-0.08x+32.61	-0.08	-0.728317896
2.2.3	y=-0.09x+26.43	-0.09	-0.586732262

Conclusions

MRI may offer a novel procedure of studying the water flows of plants. The measurement accuracy of the system surpasses by far the errors of traditional plant and water studying procedures. This non-destructive technique can be carried out on live plants offering an unlimited number of repetitions.

It has been found in the analyses of water contents in two sides of the stem that the specific water contents will be modified by the branches and lives in their locations. The variations in signal intensities of nodes confirmed the previous knowledge; the presence of water barriers could be detected readily by means of MRI.

MRI as a technique is bound to perform important roles in science and education as well. Its applications are expectable particularly among the research workers and teachers.

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THERMAL REQUIREMENT AND HEAT USE EFFICIENCY OF COTTON IN RAINFED ECOSYSTEM

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Abstract

Field experiment was conducted in cotton to study the different methods of sowing and plant geometry under rainfed condition at Agricultural Research Station, Kovilpatti. In this investigation, thermal requirements at different phenological stages, heat use efficiency and the productivity of cotton were analyzed under rainfed vertisol condition. The results revealed that cotton grown in direct seeding under augerhole method were more efficient in utilizing heat units in terms of GDD, HTU and PTU .The highest cotton yield was obtained in auger hole seeding with closer spacing by utilizing more heat energy which in turn reflected in increased heat use efficiency.

Key words: Thermal indice, Bt cotton, heat use efficiency, phenological stages, seed cotton yield.

Introduction

Cotton, being an important cash cop grown in India, plays a pivotal role in its agricultural economy. During the last decade, the existing cotton cultivars started a decline in seed cotton yield. Further in the recent past, there is short decline in cotton area due to unfavourable conditions like erratic and uneven distribution of rainfall, heavy incidence of pest and diseases and above all the prevailing market price which seldom fetches the remunerative price to the farmers. Moreover, most of the cotton crop is cultivated under rainfed condition with low yield and there is a need to exploit the yield potential of cotton crop. Recently the introduction of transgenic Bt cotton from the last 3- 4 years has sown remarkable upward trend in seed cotton yield. However, the efficient crop production packages from the modern agronomy of cotton explore the avenues for realizing the potential crop yield. Bt cotton hybrids have shown changes in vegetative and reproductive characteristics (Chen et al., 2004). This can be realized with suitable agronomic practices like plant geometry, method of sowing, balanced fertilization etc. especially under rainfed condition. The yield and other yield attributing parameters of cotton vary with the plant densities (Tomar et al, 2000; Buttar and Singh, 2007).The duration, growth and yield are decided by the thermal and photoperiod conditions experienced by the crop during its life cycle . Yield of crop can be taken as a product of rate of biomass accumulation (solar radiation dependent) and the growth duration (ambient air temperature dependent). Efficiency of conversion of heat energy into dry matter depends upon genetic factors, sowing time and crop type and the radiation use efficiency and heat use efficiency were widely used on understanding energy use of crops (Rao et al., 1999 and Sharma e al, 2000). Some modified Growing degree days (GDD) such as Helio thermal units (HTU), Photo thermal units (PTU) were employed because of air temperature is not only the factor in influencing the growth and yield of crop.

Keeping these in view, the present study was carried out to find out the growth and yield crop in relation to agro meteorological indice viz., GDD, HTU and PTU and Heat use efficiency (HTU) of cotton grown under varied production environments.

Material and methods

Field trial was conducted during monsoon season (September-October) 2007-08 at Agricultural Research Station farm, Kovilpatti, Tamil Nadu, India. The climate of the experimental site was warm and dry. The soil was heavy textured and taxonomically belonged to category of vertisol. The fertility status of the soil is low to medium. The pH ranged between 7.8 and 8.3 which were moderately saline. The experiment was laid out in split plot design with cotton Bt hybrid. The treatments consisted of method of sowing (M1-Direct seeding in flat bed: M2-Direct seeding in auger hole pit) and plant geometry (S1-100x50 cm; S2-100x75 cm; S3-100x100 cm) was assigned to main plot and subplot respectively. The auger hole pits were dug out with the help of hand operated auger machine and each hole is filled with composted coir pith. During the cropping period, a total rainfall of 424 mm was received. Weather parameters recorded at Agromet observatory, Kovilpati were collected and the derived weathers parameters were computed on daily basis. The derived parameters were accumulated from sowing to each phenological stage. GDD was computed by subtracting the base temperature from daily mean temperature as suggested by Ketring and Wheless (1989). Helio thermal units are the product of GDD and corresponding actual sunshine hours of that day. Photo thermal units are the product of GDD and the corresponding day length of that day. Heat use efficiency was computed to compare the relative performance of Bt cotton and production practices using the formula.

$$\text{Heat use efficiency} = \frac{\text{Seed cotton yield (Kg ha}^{-1}\text{)}}{\text{Accumulated heat units } ^{\circ}\text{C day}^{-1}}$$

The experimental data were analyzed statistically and the standard error for mean difference (SEd) and critical difference (CD) were worked out at 5% probability level (Gomez and Gomez, 1984) for comparison of different treatments.

Results

Thermal indice

The accumulated GDD, HTU and PTU at different phenological stages showed variation among the sowing methods (Table1). The total accumulated GDD, HTU and PTU were higher in auger hole seeding as compared to direct seeding in flat bed method. The total values of thermal indice viz., GDD, HTU and PTU from emergence to maturity were ranged from 156 to 1352 °C day $^{-1}$, 684 to 8975 °C day hr and 1840 to 15940 °C day hr respectively in case of direct seeding in auger hole pit where as the values were 99 to 1349 ^{o}C day $^{-1}$, 226 to 9676 248 °C day hr and 1173 to 15859 °C day hr for direct seeding in flat bed method. The requirements of heat units were higher during boll formation to maturity phase as compared to other stages.

Growth, yield and HUE

The results revealed that higher growth and yield attributes of cotton viz., plant height, sympodial branches, boll number and boll weight were registered in auger hole seeding which reflected on increased yield as compared to flat bed seeding (Table 2). The highest yield 1500 kg ha^{-1} was obtained in auger hole seeding method. Among the plant densities, though the closer spacing of 100x75 cm recorded lesser and on par with growth and yield attributes as compared to wider spacing of 100x75 cm and 100x100 cm, but the highest yield (1515 kg ha^{-1}) was obtained in closer spacing. The heat use efficiency computed during maturity phase showed higher value (0.61 °C day $^{-1}$) was observed in auger hole seeding with plant geometry of 100x 50 cm (0.62 °C day $^{-1}$).

Discussion

The growth and yield parameters of Bt cotton was higher in auger hole seeding might be due to a favourable environment in the early stage viz., easy facilitation of root growth, more moisture retention capacity and better seedling growth provided by this method of sowing put forth more growth and yield parameters. Further the higher thermal indice during different phenophases might have also contributed increased growth and yield attributes which ultimately resulted in increased seed cotton yield. Closer spacing 100x50 cm recorded lesser and on par growth and yield attributes but it recorded the highest yield and significantly superior to wider spacing and might be due to more number of populations per unit area influenced the yield of the crop. This is in agreement with findings of Buttar and Singh (2006). The heat use efficiency was also showed better utilization of heat in terms of solar radiation might have contributed increased growth and yield attributes and reflected on higher yield. Cotton crop with low heat use efficiency was observed in direct seeding in flat bead with wider spacing might be due to slow growth and less canopy development in the early stages. This is in agreement with the findings of Singh et al., (2002).

Conclusions

From the studies in rainfed cotton , it can be concluded that cotton grown in direct seeding by auger hole method with closer spacing were more efficient in utilizing heat units in terms of GDD,HTU,PTU and HUE which enhanced increased growth and yield parameters and finally reflected on higher yield.

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Table 1. Effect of thermal indice at different growth stages of cotton.

Growth stages	Direct seeding in Flat bed			Direct seeding in auger hole		
	GDD ^{0}Cday^{-1}	HTU ^{0}Cday hr	PTU ^{0}Cday hr	GDD ^{0}Cday^{-1}	HTU ^{0}Cday hr	PTU ^{0}Cday hr
Sowing to Establishment	99	226	1173	156	684	1840
Establishment to Square formation	571	3876	6629	613	4091	7090
Square to Boll formation	331	1583	3923	330	1709	3800
Boll formation to maturity	1349	9676	15859	1352	8975	15940
Total	2360	15361	27584	2451	15454	28670

Table 2. Growth and yield parameters and HUE on cotton

Treatments	Plant Height (cm)	Sympodial branches nos plant^{-1}	Boll nos plant^{-1}	Boll weight plant^{-1}	Seed cotton yield (kg ha^{-1})	HUE (kg ha^{-1} ^{o}Cday^{-1})
Direct seeding in flat bed	98.2	14.8	20.4	4.2	1000	0.42
Direct seeding in auger hole	107.6	18.0	30.6	4.6	1500	0.61
SEd	1.6	0.7	0.8	0.1	65	-
CD $_{5\%}$	4.1	1.8	2.1	0.2	165	-
100x50 cm	96.6	15.1	24.3	4.2	1515	0.62
100x75 cm	100.1	16.1	25.3	4.4	1235	0.51
100x100 cm	106.2	16.4	26.2	4.5	880	0.36
SEd	1.1	0.3	0.7	0.1	40	-
CD $_{5\%}$	2.3	0.7	1.4	0.2	95	-

THE SUBSIDY SCHEME OF GREEN POWER IN HUNGARY

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Abstract

In Hungary the government sponsors energy production from (1) combines heat-power generation and (2) renewable resources. The form of this subsidy is the so called, KÁT (= Subsidy for Obligatory Takeover). However, the allocation of KÁT is severely distorted in Hungary, due to the structure, which is based on produced quantities. The large power plants, which had been operated on a coal basis, utilized this market opportunity and shifted to biomass (wood) very rapidly. For this sole reason, the energy produced from alternative sources (almost exclusively biomass) has increased significantly, beyond EU prescriptions. On the one hand we can doubt the ecological benefit of this process, but this is not the topic of our current article. On the other hand, however, the current system logic guarantees as much as 82% of the KÁT allocated to these – mostly large – biomass power plants. We also propose a solution, where the basis for allocation would not be the energy quantities produced, but a system based on alternative energy potentials. Oversubsidised biomass would be limited 60% on a macroeconomic level, in order to promote solar and geothermal energy, which have the highest ecological benefit and potential in Hungary, but are more expensive.

Keywords: renewable resources, KÁT subsidy system, biomass, power plants,

Összefoglalás

A megújuló energiaforrásokból termelt villamos energia kötelező átvételéhez kapcsolt támogatás (KÁT) erőteljes aránytalanságot mutat hazánkban. Mindez a termelés alapú KÁT támogatási rendszer következménye. A hazai nagy, korábban széntüzeléses erőművek, kihasználták a támogatás adta lehetőséget és részben átálltak fatüzelésre. Ezáltal megnőtt a megújuló energiából, elsősorban biomasszából előállított áram mennyisége hazánkban, ráadásul a megújulós KÁT legnagyobb része (82%) is őket illeti. Az aránytalanságra megoldást jelenthet egy nem termelés, hanem megújuló energiapotenciál alapú támogatási rendszer, melyből a biomassza csupán 60%-ban részesülne, így az eddig háttérbe szorított nap és geotermális energia is forráshoz jutna.

1. Introduction

Hungary favours the production of green power similarly to European Union's member states, based on the directive 2001/77/EK. The country guarantees a raised takeover price to the promotion of the proportion of produced electric energy from renewable resources, which is reached by the operating of the obligatory takeover system (KÁT). The gist of the system of KÁT is that they take over the electric energy from the power stations fulfilling the conditions prescribed in Electric Power Law on a particular price fixed in advance. We call those firms combines heat-power generation, which ones sell thermal energy beyond the produced electric energy. The power generation coming true with the use of the renewable energy sources is qualified as green power, which are the solar-, wind-, water-, geothermal energies, or power produced from biomass.

The green power producers and the combines heat-power generation are affected in the obligatory takeover. The sum devoted to the operating of the obligatory takeover system is divided between the combines heat-power generation and the renewable power stations in 7/3 proportions. The obligatory takeover system (VET 9. § (2) paragraph) renewed on 1st of January 2008 share the subsidy of green power based on the proportion of produced power and does not according to the country's renewable energy potential. The authors consider this the objectionable point of the system KÁT, since it would be necessary to take not only the production in a given time but the potential of renewable energy of the country into consideration at the structure of the subsidy according to their opinion.

The allocation of KÁT subsidy concerning to renewable energy is severely distorted in favour of the biomass, since the five largest domestic thermal power stations switched to the firing of biomass partly or in whole, following the turn of the millennium. The subsidy of biomass takes 82,07% of Hungarian KÁT concerning to renewable energy (Tóth et al, 2009). Taking the country's energy potential into consideration the disproportion is visible yet, but already not standing out, moreover Hungary can accomplish the pledge put towards European Union only, according to which the 3,6% of the production of all of the electric energy will be from renewable energy until 2010.

Electricity produced from biomass is currently produced primarily in earlier coaly big power plants. The developments ensuing because of the changes of the law and economic regulations yielded the multitudinous usage of the firewood in the past years. The demand has increased for the solid biomass kinds because of the growing claim of power station stock, which lifted the prices significantly (Bai, 2003, Gergely, 2007). In as much the Hungarian thermal power stations' considerable part produces the electricity with tree firing in the future, our domestic forests will be in danger (Winkler, 2004).

The switching of domestic five big (earlier) coal heating power stations to tree or mixed firing made it possible, letting Hungary over fulfil his pledge and 5,3% of the domestic current production derive from renewable resources already in 2008.

2. Materials and Methods

We examined the establishment of payments of the earlier (KÁP) and the present subsidy for obligatory takeover (KÁT) based on the data of MAVIR zRt. We compared the percentile proportions of the amounts devoted to the subsidy with the proportion of green power produced in Hungary and the renewable energy sources of which use can be made potentially in the country.

The quantity of the biomass is around 100 PJ which can be utilized really in Hungary (Hajdu, 2006). The half of this quantity may derive from the growing of energy plants, while the other half derives from the use of natural biomass. We used the data of Ferenc Bohoczky from 2008 for the examination of the renewable energy sources which can be utilized potentially, who values the quantity of biomass of which use can be made really in Hungary together with the growing of the energy plants 94 PJ.

3. Results

The table 1 exemplifies our calculations about the electricity which is produced from the renewable energy. It can be read, that the biomass gets the 47% of the renewable energy sources which can be utilized potentially in Hungary. If we take the cultivation of energy plants into consideration, the value is modified to 62%. The ratio grows to 90% if we only count with the renewable energy sources utilized currently.

Table 1: Renewable energy potential and the subsidy in Hungary

	geothermal	solar	biomass	wind	water		sum
Renewable enegy in Hungary							
potential (PJ/year)	50,00	4,00	58,00	7,20	5,00		124,20
currently utilised (PJ/year)	3,60	0,12	46,00	0,54	0,70		50,96
potential, including energy plants (PJ/year)			48,00				172,20
potential (%)	40,26	3,22	46,70	5,80	4,03		100,00
utilised (%)	7,06	0,24	90,27	1,06	1,37		100,00
potential, including energy plants (%)	29,04	2,32	61,56	4,18	2,90		100,00
			fire wood burning			biogas	
KÁT 2008							
renewable KÁT (Billion HUF)	0,00	0,00	15,10	2,40	0,50	0,40	18,40
payment (%)	0,00	0,00	82,07	13,04	2,72	2,17	100,00
Electricity production form renewable energy in 2007							
produced electricity (GWh)	0,00	0,00	1194,00	107,00	203,00	26,00	1530,00
procent of the production (%)	0,00	0,00	78,04	6,99	13,27	1,70	100,00

source: own table, on the basis of the data of Tóth et. al. (2009) and Bohoczky (2008)

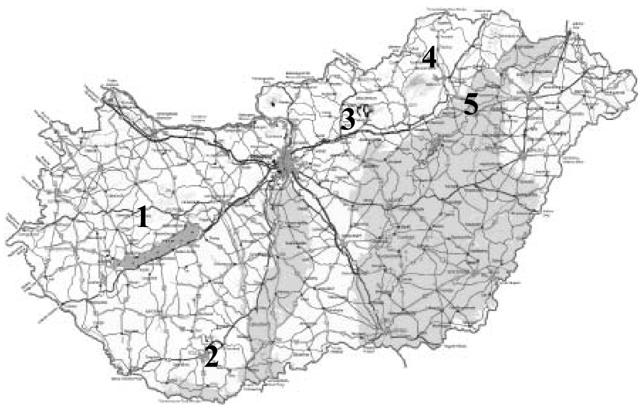
78% of the green power produced in Hungary derives from power stations with biomass firing.

Studying the KÁT data from the year of 2008 we realize that the biomass KÁT subsidy is 82% of the amount of renewable KÁT. The wind power got 13,04% of the subsidies, opposite this the water energy and the biogas production got one by one only 2,17%. Electricity was not produced from solar energy (apart from some households) and from geothermal energy. That is why the above mentioned two sectors did not receive any subsidy.

Studying the data of the table 1 we can get to the following statement: the electricity production from biomass gets the largest sum of KÁT subsidy. The above mentioned data was not only the peculiarity of the year 2008, but the feature of the earlier obligatory takeover system. Electricity can be produced in the earlier coal-firing big power stations from renewable energy undoubtedly the most economically, so that we modify the combustible to biomass. The Hungarian big power stations recognised this quickly, so the undermentioned five largest domestic power stations have already used biomass in their boilers in 2008, which is contemplated on the figure 1:

- Ajka: Bakony thermal power station (1)
- Pécs: Pannon thermal power station (2)
- Visonta: Mátra thermal power station (3)
- Kazincbarcika: Borsod thermal power station (4)
- Tiszaújváros: Tiszapalkonya thermal power station (5)

Figure 1: The five largest Hungarian biomass firing power station



source: Pinter et al, 2009.

After the five largest domestic big power stations have switched to tree firing they automatically got the obligatory takeover subsidy of the electricity. Because of the KÁT subsidy is commensurable with the produced electricity; the power stations burdened the cash register of the subsidy of the obligatory takeover with their conversion, which expense was shifted upon the consumers partly.

The production of electricity from biomass amounted the 82% of the "renewable KÁT" in 2008 and the other renewable energy sources, which were sidelined willy-nilly hereby, got only the residual 18% subsidy. Electricity production from wind energy was 13,04% from the "renewable KÁT" and the biogas production was only 2,17%. It is important to know, that the already existing, generator firms receive the KÁT subsidy after their electric energy production, but also important to emphasize, that the KÁT subsidy is not in harmony with the expense of an investment producing energy from renewable energy sources. Obvious that a green field investment may not compete always with the indicators of return of an existing firm's transformation. Because of the above mentioned argument, the domestic thermal power stations switched over to the tree firing have become the first green power producers in Hungary.

The quantity of the renewable energy which can be exploited in Hungary would be necessary to take into account to allocate the subsidy of the obligatory takeover system according to the authors' proposal. Based on the table 2, the electricity production of the firm and the gas condition biomass would get together only 62% of the KÁT independently of the current yearly electricity production but naturally commensurate with the electricity production a year before.

The geothermal and solar energy have been used economically mostly for heating and not for electric production in Hungary till now.

The authors' proposal in accordance with the country's energy potential would motivate the use of renewable energy sources of which advantage is not taken yet. It is true, that the investment subsidies are applied for this purpose, however these prove to be too little.

An expert commission should define the necessary appreciated renewable energy potential for the new KÁT system, in which the representatives of the single renewable energy sources take part in an identical proportion.

Table 2:
The proposal of the distribution of the new KÁT subsidy system

	geothermal	solar	biomass	wind	water		sum
Renewable enegy in Hungary							
potential (PJ/year)	50	4	106	7	5		172
potential (%)	29	2	62	4	3		100
Electricity production form renewable energy in 2007			fire wood burning			biogas	
produced electricity (GWh)	0	0	1194	107	203	26	1530
procent of the production (%)	0	0	78	7	13	2	100
Proposal of the KÁT support distribution (%):	29	2	60	4	3	2	100

source: own calculations based on the data of the table 1

Based on the table 2 the geothermal energy would partake 29%, the solar energy 2%, the firm biomass 60%, the biogas 2%, the wind power 4% and the water energy would partake 3% from the yearly KÁT. Verifiable, that instead of 82% KÁT payment in 2008, merely 60% would be left for the biomass, comparing the data of the table 2 with the data of the table 1. This change could discharge the domestic forests, and so could disappear it's burning up, which seems in many cases irresponsible. Based on the new subsidy scheme, the subsidy of the wind power would present 4% of the KÁT payments instead of the current amount of 13%. The subsidy of the water energy and the biogas would not change practically, while the solar and the geothermal power stations would be the unambiguous winners of this change.

According to the authors' proposal, while electricity is not produced through solar and geothermal energy, the remaining amount of KÁT should subsidize the stimulation of their realisation and it would be possible to be devoted for the supplement of the existing sources initially. The KÁT subsidy should be divided between the green energy producers according to the proportion of the electricity production. Based on the table 2, the disproportion of the present KÁT subsidy system of the biomass and the wind power is considerable.

4. Discussion

The biggest difference between the author's new KÁT subsidy system and the current scheme is that the new one is based on sustainability and not on the interest on mostly multinational investors. The authors emphasize it, that for entering their new KÁT subsidy system, it is necessary to measure again Hungary's renewable energy potential concentrating to electricity production and then to modify the suitable data based on the new research. The loser of the new subsidy scheme would be the firm biomass and the wind power. The authors suggest the reduction of wood-burning power stations' subsidy immediately without all transitions, based on their research. Subsidizing the electricity production from wind power would be financeable from geothermal energy subsidy but only incipiently. The new system would reduce the subsidy of the wind power from 13% to 4%, but this 9% can be subtracted from the 29% of the geothermal energy too, but the subsidy percentage (of 13%) of the wind power can not be risen. The necessity of the remaining 20% of the "renewable KÁT" for the geothermal energy can be claimed by the considerable investments cost. The present investment subsidies would be possible to complement by the 2% allotted to solar energy, so projects could be started which would utilize the solar radiation.

The authors propose that the given yearly KÁT subsidy sum should be defined according to a particular percentage of prizes, which was flowed in from the electricity consumption in the previous year. The overload of the consumers' purse would be avoidable this way and the dislike for the electric energy produced from renewable energy sources would decrease.

The benefit of the new KÁT subsidy system introduced in the present study is that it takes the country's natural conditions into consideration and do not concentrates only on interests of current investors. So this schema guarantees more stable and more calculable obligatory takeover system in long term, which benefits affect consumers and producers equally.

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DIGITAL LEAF AREA MEASUREMENT AND ITS APPLICATION IN PRACTICE

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Abstract

Evaluation and processing of experiments became more simple and accurate by using digital technology and the Internet. The subject of our study was to compare analogue (printed methods and LI-COR LI-3000A) and digital leaf area measurement methods (using Canon EOS 10D and 1D Mark III digital cameras, Hewlett-Packard HP4670c scanner and Sony Ericsson K750i mobile phone) using reference areas and leaf areas of 20 plants (agronomic and horticultural crops). Our results showed that digital methods proved to be useful and accurate during the data processing of experiments. Apart from the advantages, several sampling and surveying methods should be also considered. Advantages and disadvantages of analogue and digital leaf area measurement methodologies are summarized in our present paper.

Keywords: image processing, leaf area measurement, digital camera, scanner

Összefoglalás

A digitális technika és az Internet elterjedésével a kísérletek kiértékelése és feldolgozása egyre egyszerűbbé és megbízhatóbbá válik. Vizsgálataink során célunk volt, hogy a hagyományos levélfelület-mérési módszereket (lenyomatos eljárás és LI-COR LI-3000A levélfelületmérő) összehasonlítsuk a digitális képfeldolgozásra épülő módszerrel (Canon EOS 10D és 1D Mark III digitális fényképezőgépek, Hewlett-Packard HP4670c szkenner, Sony Ericsson K750i mobiltelefon használatával) referenciaterületek és 20 növénykultúra (szántóföldi és kertészeti) levélterülete alapján. Az eredményekből kiderült, hogy a digitális levélfelület-mérési módszerek jól használhatók a kísérletek kiértékelésénél. Előnyei mellett azonban néhány felvételezési és értékelési módszerre célszerű odafigyelni. Jelen publikációban összefoglaljuk a hagyományos és a digitális levélfelület-mérés előnyeit és hátrányait.

Kulcsszavak: képfeldolgozás, levélfelület-mérés, digitális fényképezőgép, szkenner

Introduction

By the present days, rapidity has become one of the most important factors in assessing experiments. The sooner data can be obtained, the sooner results are available and can be used in practice. Data information (measurements, for example input images of leaf areas) may be sent from the field with a mobile phone or wireless Internet connection to the laboratory staff for assessment and interpretation. Data may be continuously forwarded from the device to a computer by Wifi, Bluetooth or wireless connection.

In agricultural and environmental sciences, the relationship between leaf area (i.e. the assimilation area of plants) and yield levels is very important (Anda – Tóbiás, 1999). This is one of the parameters used to describe productivity, serving as a basis of plant growth analyses in physiological studies. Main parameters of expression are: leaf area index (LAI), leaf area density (LAD), leaf area ratio (LAR), specific leaf area (SLA), primer production rate (PPR) (Pethő, 1993).

Several approaches are commonly used for the measurement of plant leaf area: the Montgomery-formula, print-methods, application of planimeters etc. (Anda-Tóbiás, 1999). Digital methods may be categorized in two main types (Berke et al., 1993; Berke, 1994):

1. Partly digital methods (using analogue and digital devices together) and
2. Fully digital (all devices are digital).

Materials and methods

Besides of leaves from a monocotyledonous and a dicotyledonous plant as reference leaves, as well as exactly defined square areas, test plants selected for the study have represented the typical forms of crops from arable land and horticulture. The following crops were selected: tomato (*Lycopersicon lycopersicum* L. Karsten ex. Farwell.), soybean (*Glycine max* L. Merrill), sugar-beet (*Beta vulgaris* L. var. altissima Doell.), chick-pea (*Lathyrus cicera*), winter wheat (*Triticum aestivum* ssp. vulgare), oats (*Avena sativa* L.), rape (*Brassica napus* L. ssp. oleifera), rye (*Secale cereale* L.), spring barley (*Hordeum vulgare* L.), sunflower (*Helianthus annuus* L.), maize (*Zea mays* L.), english clover (*Trifolium pratense* L.), potato (*Solanum tuberosum*), alfalfa

(*Medicago sativa* L.), flax (*Linum utitatissimum* L.), grape (*Vitis vinifera*), bell pepper (*Capsicum annuum* L.), carrot (*Daucus carota* L.), beans (*Phaseolus vulgaris* L.), and green peas (*Pisum sativum* L.).

The experiment was carried out in April 2008 under greenhouse conditions at the University of Pannonia, Georgikon Faculty, Department of Crop Production and Soil Science, Division of Soil Science and Agrochemistry, in pots containg 4 kilograms of a mixture of a calcareous chernozem soil and mould with a ratio 3:1. Sampling and the images were taken at the plant age of 6-8 weeks (between 17 June and July 2008).

The following devices were used to compare the leaf area measurements:

Squared-plotting paper

For the printed methods, the leaves were drawn round on a squared-plotting paper and the area was calculated. The area was considered as the reference area and results from the other methodologies were compared to this.

LI-COR LI-3000A

The LI-3000A work with infrared waves can be used both with battery and mains voltage so it can be easily applied for field studies. Under laboratory conditions, the leaves are transferred to the measurement device on an endless band, which consist of two parts: an infra red light radiate by diode line and a radiation LED receiver. The infra red radiation will be absorbed by the examined leaves, so the leaf area can be concluded from the under covered lights. The appliance is suitable for routine measurements when the leaves are transferred continuously on the endless band and the results become aggregated on the display. The sample must pull between two sides of the head when using with battery, so the length measurer wire must be held together with the leaf. The disadvantage is that the part of the leaf held cannot be measured.

Readings on the display can be obtained in cm^2 with two-tenth accuracy in this case, too. The device is able to measure both average and maximum leaf width and length. The measured data are stored and may be forwarded to the computer when it is connected (LI-COR, 1988).

Canon EOS 10D and 1D Mark III digital cameras

The images were taken with Canon EOS digital single lens reflex cameras, the main parameters are the following:

Canon EOS 10D	Canon EOS 1D Mark III
• Sensor: 6 megapixel	• Sensor: 10 megapixel
• File formats: JPEG, RAW	• File formats: JPEG, RAW
• Sensitivity: ISO 100-3200	• Sensitivity: ISO 100-6400
• Shutter speed: 1/4000-30sec	• Shutter speed: 1/8000-30sec

(Canon Inc. 2003, 2007)

Hewlett-Packard HP4670c scanner

Hewlett-Packard HP4670c scanner was used to digitalize the leaves; its main parameters are the following:

- Optical resolution: 2400 dpi,
- Colour depth: 48 bit,
- Scan area: 21,6x29,7 cm
- File formats: BMP, TIFF, GIFF, PDF, HTML, JPEG, FPX, DCX, PCX, RTF, CRV, PNG,
- Accessories: transparency adapter (Hewlett-Packard, 2003).

Sony Ericsson K750i

It can be used in GSM 900, 1800 and 1900 networks. We can send the data with Bluetooth or Infra red. It has also a 2 mega pixel camera. Its 34 Mbytes storage can be completed to 2 Gbytes (Sony Ericsson, 2005).

The following computer configuration was used to image procession:

- AMD Athlon XP 3200+, 2,21 GHz processor,
- 512 Mbyte RAM,
- 80+300 Gbyte hard disk,
- Pioneer 110 DVD reader/writer,
- Samsung SyncMaster 765 MB monitor (Maximum resolution 1600*1200),
- Mouse,
- Floppy drive.

The following software were used to process:

- Adobe Photoshop CS3: Professional image processing software with IBM PC and Macintosh version.
- Irfanview 4.2: Viewer, categorizer and image processor software.
- Microsoft Excel 2003: Table manager part of the Microsoft Office 2003 software package.
- Canon Camera RAW: Image converter which converts camera specific images to JPEG or TIFF.
- Canon ZoomBrowser EX 5.8.: Canon's image processor and categorizer.

Description of the digital leaf area measurement

The method presented by the example Adobe Photoshop CS3 professional image processing software but it can be carried out applying other similar image processing software. At first reference images (millimetre scale on the sides of the images) should be opened, wherewith the area of the pixels was calculated if manufacturer's standards are not available. In the next step the images containing the leaves were opened with the software. The leaves were cut around as closely as possible to avoid mistakes. Then 'Median' filter was applied thus point-like noise were reduced. 'Threshold' function was selected thus the object was separated from the background. After 'Threshold' function the pixels not wholly covered was corrected which appeared mostly at the protuberances of the veins. The object pixels were counted with the help of the 'Histogram' option and they were multiplied by the pixel area thus the area of the leaves was obtained in cm^2 (Grósz – Sárdi – Berke, 2007).

Results

Parameters of the digital leaf area measurements

Well defined areas were selected as a basis, thus 9, 25 and 100 cm2 squares from squared-plotting paper we chosen. For the calibrations it was decided not to use leaves as the protuberances of the veins and the turn up of the leaves could be result in more mistakes. By the squared-plotting paper, possible human mistakes should be considered e.g. inaccurate cutting off the squares. The level of the error always was about 0,5%.

The effect of the angle position of digital camera on the result of leaf area measurements

Unit (10x10 cm) area was placed over the work-table. The camera were placed on a stand and rotated from 90°to 30°by 5°. Four images were taken in every position and the data were measured by using the Photoshop program. The rotation angle was decreased, the leaf area was changed significantly, and its volume became larger with the rotation angle. The rotation angle, the differences between the print-methods and digital methods with rotated camera is shown in the table (Figure 1, Appendix 1). It was established that the stand of the camera at the right angle is very important.

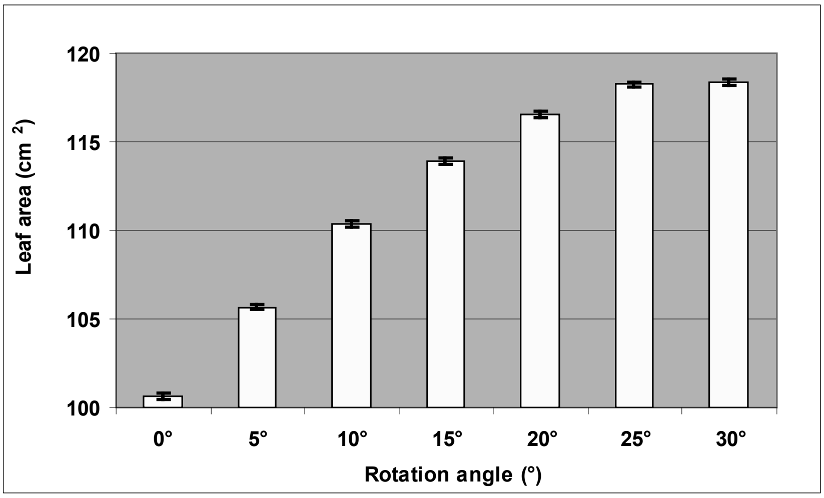

Figure 1: The effect of the angle position of digital camera on the result of leaf area measurements

The effect of sensor sensitivity on the result of leaf area measurements

In this study the unit (3*3 cm, 5*5 cm, 10*10 cm) areas were photographed with different ISO sensitivity.

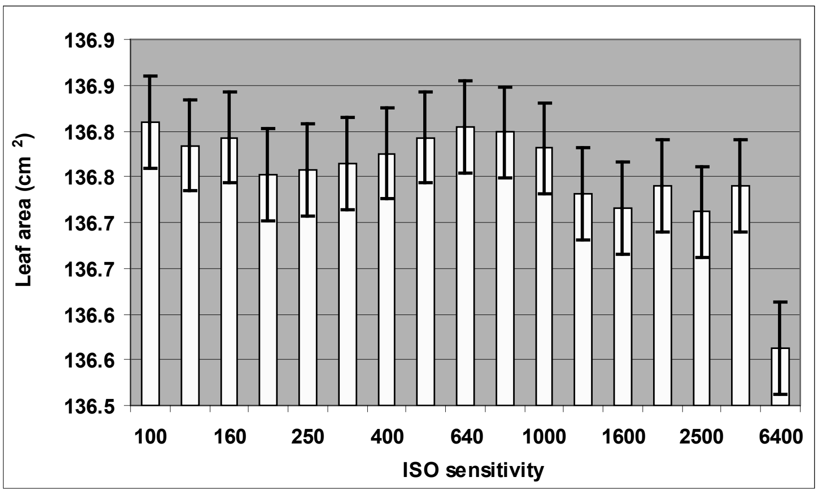

Figure 2: The effect of sensor sensitivity on the result of leaf area measurements

These were the following values: ISO 100, 125, 160, 200, 250, 320, 400, 500, 640, 800, 1000, 1250, 1600, 2000, 2500 and 3200. Measurements were made in four replicates for the statistical analyses. From the results it was evident that taking photos at different ISO sensitivity did not cause significant differences and the measured deviation has originated from noise (Figure 2, Appendix 2).

The effect of the lenses applied on the result of leaf area measurements

In this experiment the effect of different lenses on the result of leaf area measurements were evaluated. The following lenses were connected to the Canon EOS 10D body:

- Sigma 35-80mm at 35mm,
- Sigma 35-80mm at 50mm,
- Sigma 35-80mm at 80mm,
- Canon EF 50 mm at 50mm,
- Sigma 105 mm Macro at 105 mm.

The largest difference was found at the Sigma objective 35-80 mm at 35 mm. At the others there were not significant differences (Figure 3, Appendix 3). The distortion caused the big difference. This mistake – when the lens distortion is known – could be corrected with special software (e.g. DxO).

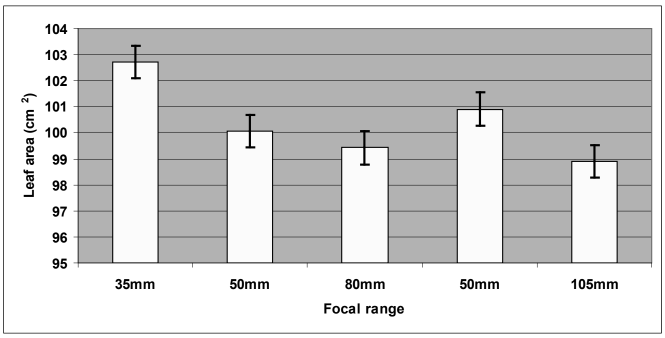

Figure 3: The effect of the applied lenses on the result of leaf area measurements

The effect of aperture values on the result of leaf area measurements

The effect of aperture values were examined with an aperture line from 1,8 to 22 using a Canon EF 50 mm f 1,8 lens on a Canon EOS 1D Mark III body. The flaw was found from 0,91% to 1,65%. Significant differences were found at some results (Figure 4, Appendix 4). The differences were found because the lenses mapping.

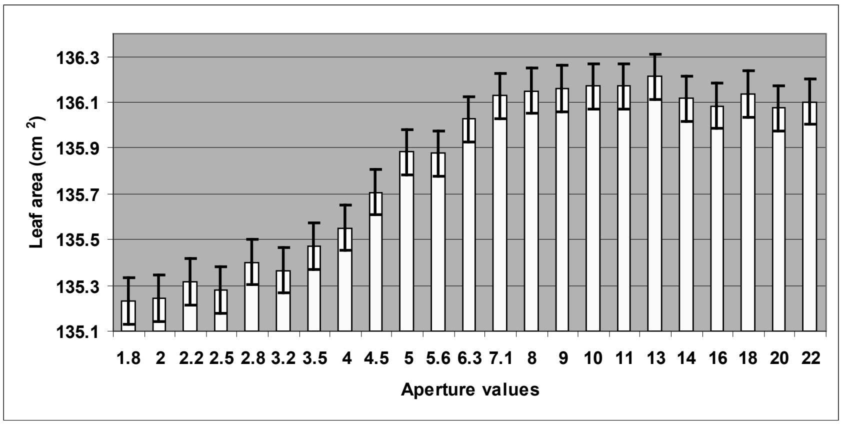

Figure 4: The effect of aperture values on the result of leaf area measurements

Possibility of using mobile phones

Photos were taken with 3 resolutions (160*120, 640*480 and 1632*1224) with a Sony Ericsson K750i mobile phone. The lens of the mobile phone gives a 28 mm equivalent visual angle. Reducing the resolution the difference is becoming larger. The exact indication of squared-plotting paper in the smallest resolution could be a problem. At the largest resolution the difference comes from the wide angle distortion. Comparing the results with a digital camera unit having bigger sensor and better quality lenses it could be seen that the error is almost double (Figure 5, Appendix 5).

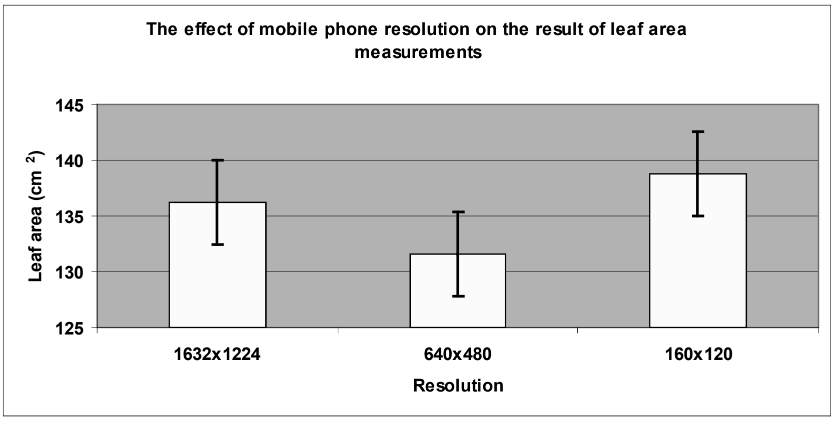

Figure 5: The effect of mobile phone resolution on the result of leaf area measurements

The effect of different devices on the result of leaf area measurements

The following methods were used for the comparison: squared-plotting paper (as a reference), LI-COR LI-3000A (table and portable) analogue leaf area meter, Hewlett-Packard HP 4670c scanner and Canon EOS 1D Mark III body with Canon EF 50 f 1,8 lens.

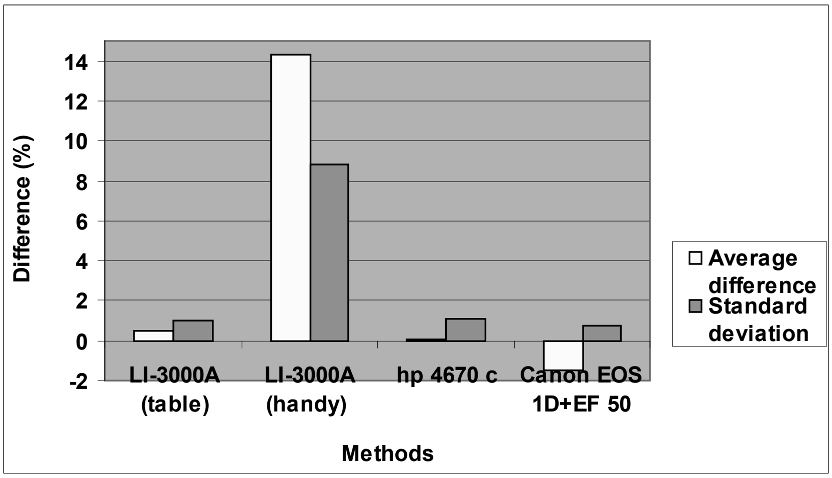

Figure 6: Comparison of results of leaf area measurement methods to the squared-plotting paper with mean and standard deviation (n=50)

To process images Adobe Photoshop CS3 professional image processing software was used. For the comparison 3*3, 5*5, 10*10 squared-plotting paper as well as monocotyledons and dicotyledonous leaves were used. From the results it was evident that the methodology with lowest accuracy was the handy leaf area measurement method because of its possible mistakes. Considering the 1.5 percent margin of error for squared-plotting paper from the literature data, differences were not significant compared to the other methodologies (Figure 6, Appendix 6).

The comparison was made with the test plants too. Differences were considerably bigger because of the inhomogenity of leaves.

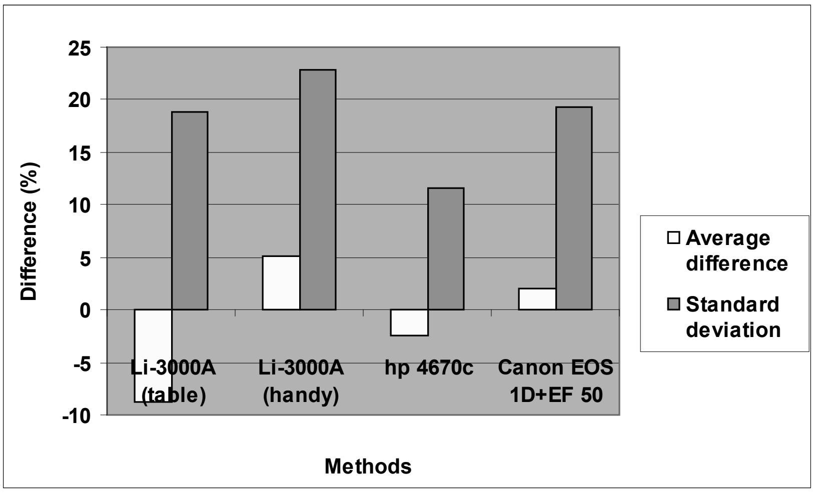

Figure 7: Comparison of results of leaf area measurement methodologies to the squared-plotting paper with mean and standard deviation (n=160)

Leaves of several plant species could not be measured with certain methodologies:

- Squared-plotting paper: carrot,
- Li-3000A mobile version: chick-pea, flax.

Carrot leaves couldn't be measured with squared-plotting paper because of the compound leaf while others could be measured satisfactory. LI-3000A mobile version could not be used for measuring chickpea and flax because of the small size of leaves they could not be held. The mobile leaf area measurer gave the most inexact result considering both the test areas and plants due to the usage conditions. The digital scanner method gave the most exact result in both cases. Biggest standard deviation was obtained by the different press approaches and the variable leaf morphology (Figure 7, Appendix 7).

Conclusions

Summarizing our results it can be stated that digital leaf area measurement is a useful, modern methodology in the scientists' hands with its advantages: low costs, rapidity, increased accuracy, very good reproduceability and automatization. On the other hand, it has a few disadvantages (special set up conditions, special knowledge). From the results of our experiments it could be stated that the stand of the camera at the right angle was very important. Reducing the measured deviation could be obtained using low ISO value, at good lightning conditions, which originated from noise. Good quality lenses and sensors may decrease differences.

Comparing the results with a digital camera unit having bigger sensor and better quality lenses it was evident that the error was considerably higher. From the results it was evident that the methodology with lowest accuracy was the handy leaf area measurement method because of its possible mistakes. Considering the 1.5 percent margin of error for squared-plotting paper from the literature data, differences were not significant compared to the other methodologies. Digital leaf area measurement can be used in practice on the same level of efficacy with other methods. However, it must be mentioned that development of a special software could help to automatize and increase the measuring rapidity.

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Appendixes

Rotation angle	**0°**	**5°**	**10°**	**15°**	**20°**	**25°**	**30°**	**LSD 5%**
Difference	0.61 %	5.68 %	10.38 %	13.90 %	16.53 %	18.25 %	18.38 %	0.17 %

Appendix 1: The effect of the angle position of digital camera on the result of leaf area measurements

ISO sensitivity	**100**	**125**	**160**	**200**	**250**	**320**	**400**	**500**	**LSD 5%**
Difference	0.59 %	0.58 %	0.58 %	0.55 %	0.56 %	0.56 %	0.57 %	0.58 %	0.03 %

ISO sensitivity	**640**	**800**	**1000**	**1250**	**1600**	**2000**	**2500**	**3200**	**LSD 5%**
Difference	0.59%	0.59%	0.57%	0.54%	0.53%	0.54%	0.52%	0.54%	0.03%

Appendix 2: The effect of sensor sensitivity on the result of leaf area measurements

Sigma 35-80 (35mm)	Sigma 35-80 (50mm)	Sigma 35-80 (80mm)	Canon EF 50 (50 mm)	Sigma 105 Macro (105mm)	LSD 5%
2.71 %	0.48 %	0.58 %	0.91 %	1.11 %	0,51 %

Appendix 3: The effect of the applied lenses on the result of leaf area measurements

Aperture	1,8	2,0	2,2	2,5	2,8	3,2	3,5	4	LSD 5%
Average difference	0.92 %	0.93 %	0.98 %	0.96 %	1.05 %	1.02 %	1.10 %	1.16 %	0.07 %

Aperture	4,5	5	5,6	6,3	7,1	8,0	9,0	10,0	LSD 5%
Average difference	1.27 %	1.41 %	1.40 %	1.51 %	1.59 %	1.61 %	1.61 %	1.62 %	0.07 %

Aperture	11,0	13,0	14,0	16,0	18	20	22	LSD 5%
Average difference	1.62 %	1.65 %	1.58 %	1.56 %	1.59 %	1.55 %	1.57 %	0.07 %

Appendix 4: The effect of aperture values on the result of leaf area measurements

Resolution	160*120	640*480	1632*1224	LSD 5%
Difference	3.58 %	2.56 %	2.12 %	1.78 %

A*ppendix 5: The effect of mobile phone resolution on the result of leaf area measurements*

Methods	LI-3000A (table)	LI-3000A (handy)	hp 4670 c	Canon EOS 1D+EF 50
Average difference	0.45 %	14.35 %	0.02 %	-1.50 %
Standard deviation	1.01 %	8.84 %	1.07 %	0.72 %

Appendix 6: Comparison of results of leaf area measurement methods to the squared-plotting paper with mean and standard deviation (n=50)

Methods	LI-3000A (table)	LI-3000A (handy)	hp 4670 c	Canon EOS 1D+EF 50
Average difference	-8.73 %	5.17 %	-2.43 %	2.10 %
Standard deviation	18.80 %	22.77 %	11.53 %	19.25 %

Appendix 7: Comparison of results of leaf area measurement methodologies to the squared-plotting paper with mean and standard deviation (n=160)

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