FOLIA OECOLOGICA – vol. 37, no. 1 (2010). ISSN 1336-5266

Soil water availability in a short rotation poplar coppice (*Populus nigra* × *P. maximowiczii*) in Czech-Moravian Highlands

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Abstract
Fischer, M., Trnka, M., Kučera, J., Žalud, Z. 2010. Soil water availability in a short rotation poplar coppice (*Populus nigra* × *P. maximowiczii*) in Czech-Moravian Highlands. *Folia oecol.*, 37: 23–34.

There are presented results of a study of soil moisture dynamics, its spatial patterns and soil water availability under poplar coppice (*Populus nigra* × *P. maximowiczii*). The study took place in a short rotation poplar coppice culture (SRC) situated in the locality Domanínek (the Czech Republic, 49°32' N, 16°15' E, 530 m a.s.l.). Generally, the soil water content increased with the depth throughout the whole soil profile 0–0.95 m. The driest period occurred towards the end of summer, within an almost one month-long period without any precipitation. In this time, also the highest spatial variability was recorded. The water content in soil profile reached its highest value, and the spatial variability was the lowest, at the beginning of spring after the snow had melted and also after prolonged rainfall episodes during summer. The response of poplars to the water stress was analysed, and it was noted that the growth starts to be significantly limited at half of the range between the field capacity and the wilting point. The goal of the overall study is to identify correlations between the biomass increment rates and meteorological, planting and ecological factors to allow for better selection of SRC growing areas and more precise yield predictions.

Key words
short rotation coppice, soil moisture spatial and temporal patterns, water availability

Introduction

Short rotation coppice (SRC) has recently received increased attention as a renewable source of biomass for energy in the EU countries. The SRCs can become an important source of renewable energy – mainly due to their high biomass yields, good combustion quality (as solid fuel) and comparatively low biomass production costs (Kauter et al., 2003). In addition to its bioenergy potential, SRCs have many other ecological advantages – e.g. positive impacts on biodiversity (small mammals, birds, insects, etc.), nutrient capture, soil protection from wind and water erosion) and also better water management in ecosystems (Isebrands and Karnosky, 2001). More recently, the importance of plantation forestry as a greenhouse gas mitigation option, and the need to monitor, preserve, and enhance terrestrial carbon stocks have been recognized by the United Nations Framework Convention on Climate Change in the Kyoto protocol (Updegraff et al., 2004).

The largest areas of SRC (totally a few thousands of hectares) are situated in Scandinavia, Germany, UK, Italy, Belgium and France (Slatter et al., 2001; Kauter et al., 2003). The main reason why the plantations of SRC are not so widely-used is the economic situation, as there must compete with fossil fuels, other renewable energy sources, as well as residual biomass from the agriculture and wood-processing industry. Furthermore, in most cases, SRC is inferior under the given economic and political conditions (Kauter et al., 2003). One of the ways how to increase the SRC areas could be not only to offer recently supplied grants but also to optimize the technology of planting SRC on farmland. Selecting areas and establishing the SRC (in the case that the owner is going to put to use the grants) is ensured according to legislation in cooperation with accredited experts and in terms of the project (e.g. Weger and Havlíčková, 2003). The estimation of biomass production is subjective and mostly takes into account the genotype of the plant, while the role of meteorological, soil, phytopatological and herbological conditions at the given site is not fully appreciated. Therefore the use of production ecology methods that are based on mathematical modelling of growth and evolution of the plants seems to be a very promising approach. Such models which are based on exact measurements of the biotic processes and their linking with abiotic environment and subsequently formulated to general algorithms are very useful just for making decisions about where, how, and in some cases even which clones would be most suitable for planting. However using these tools requires a sufficient number of high-quality experimental data to calibrate and verify the models.

The responses of poplars and willows to drought may be the key constraint to productivity since their natural distribution and productivity are closely related to the seasonal availability of soil water (Braatne et al., 1992; Deckymn et al., 2004; Lindroth and Båth, 1999). For that reason the evaluation of soil moisture and its temporal and spatial patterns in poplars plantation is the main aim of this study. The results should contribute to a development of modelling schemes described above.

Material and methods

In April 2002, a high-density experimental field plantation for verification of the performance of poplar clone J-105 (*P. nigra* × *P. maximowiczii*) with the total area of 4 ha was established in Domanínek (Czech Republic, 49°32′ N, 16°15′ E and altitude 530 m a.s.l.). The plantation was established on agricultural land previously cropped predominantly for cereals and potatoes. Hardwood cuttings were planted in a double row design with inter-row distances of 2.6 m and spacing of 0.7 m within rows accommodating a density of 9,000 trees/ha. Soil conditions at the location are representative of the wider region with deep luvic Cambisol influenced by gleyic processes and with a limited amount of stones in the profile. The site itself is situated on a mild slope of 3° with an eastern aspect and is generally subject to cool and relatively wet temperate climate typical for this part of Central Europe with mingling continental and maritime influences. Although the area does not provide optimal conditions for SRC based on *Populus* sp. clones, the site itself is highly suitable for planting due to deep soil profile (Trnka et al., 2008).

In May 2007, an array of 16 access tubes was installed into the soil for portable datalogging with a PR1 profile probe (Delta-T Devices Ltd., UK) – a system measuring dielectric properties of soil, which are straight depending on soil water content. PR1 profile probe enable to evaluate volumetric content of soil water [%] in different depth (0.1, 0.2, 0.3 and 0.4 m). The layout of access tubes is designed to record differences in soil moisture between double rows and inter-rows and the soil moisture variability itself within the investigated area which is roughly 600 m^2 large. Readings were taken usually once a week. In July 2007, 2008 and 2009, soil sampling took place and the field capacity with the wilting point was determined together with other useful soil characteristics like bulk density, textural composition, etc.

In July 2008, 14 m high mast with system for measuring actual evapotranspiration by Bowen ratio (EMS Brno, Czech Republic) was placed in the centre of the poplar plantation. At the same place below ground, three sensors EC – 20 (Decagon Devices, USA) for measuring volumetric water content of soil and six gypsum blocks (EMS Brno) to measure soil water potential were accommodated in the depths 0.1 m, 0.3 m and 0.9 m. All sensors were connected to datalogger ModuLog 3029 (EMS Brno) and measuring step was adjusted to measure each 2 minutes and to store each 10 minutes. The three sensors EC – 20 and PR1 profile probe were calibrated through gravimetric method in order to increase measurement precision.

At the same time, the tipping bucket rain gauge MetOne 370 (MetOne Instruments, USA) was placed next to the poplar plantation.

Soil water availability was determined as an amount of soil water content [mm] up the level of wilting point. It was expressed for particular depths and summarise for soil profile. In the case of portable RR1 profile probe, the soil profile was 0.45 m deep and for the three permanent sensors was 0.95 m deep. The particular depths in the profile 0–0.95 which were not measured (namely 0.15–0.25, 0.35–0.45, 0.45–0.55, 0.55–0.65, 0.65–0.75 and 0.75–0.85), were simplified calculated using the weighted averages from the values of measured depths.

For estimating biomass increment and its reaction to soil water availability an array of 40 mechanic DB 20 and 3 automatic dendrometres DRL 26 (EMS Brno) were fixed to trunks at the breast height. These dendrometers are designed for long-term registration of tree trunk circumference via stainless tape that encircles the tree trunk. The values of increment of stem circumferences or diameters are very useful because they could be subsequently converted through the allometric equation to increment of biomass (e.g. Fajman et al., 2009). In this work we used the average values from the three automatic dendrometres and correlated them with the records of available soil water content measured by the three permanent buried sensors EC – 20.

Results

The course of mean soil water volumetric content during the seasons 2008 and 2009 is shown in Fig. 1. It is evident that the second of the observed years was the wetter one. There are two peaks in the dynamics of soil moisture during the year 2009. The first peak is linked to soil saturation with water after snow melting at the beginning of spring and the second one is associated with strong summer rainfall**.** On the other hand, the lowest values were recorded at the end of summer and first part of autumn in both monitored years.

The spatial soil moisture variability is expressed by using a standard deviation at the Fig. 2. It is obvious that values of the standard deviation decrease with the higher mean soil moisture and on the contrary during the drier period increase. This relationship is especially true for the three deeper soil layers. In the case of superficial layer (0–0.15 m), no significant linkage for the mean soil moisture and standard deviation is observed.

The relationship between the mean soil moisture within the plot and the standard deviation is depicted in Fig. 3 and numeric expression through the correlation coefficients is placed in Table 1. We can observe that the absolute variability, i.e. the standard deviation, increase almost linearly with decreasing soil moisture. Furthermore, Fig. 3 shows that this relationship is depth dependent, with important difference between the superficial depth (0–0.15 m) and more profound depths (0.15–0.45 m). We can also recognise here that the depths 0.2 and 0.4 m reach highest variability. On the contrary the depth 0.3 shows the lowest variability of soil moisture. Depletion in soil moisture together with

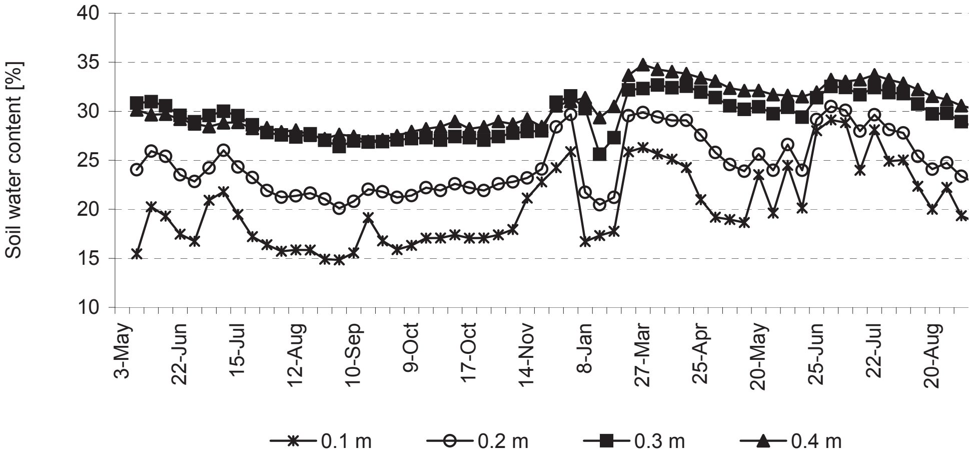

Fig. 1. Seasonal dynamics (2008–2009) of soil moisture in different depths (0.1–0.4 m) expressed in moisture volumetric percentage

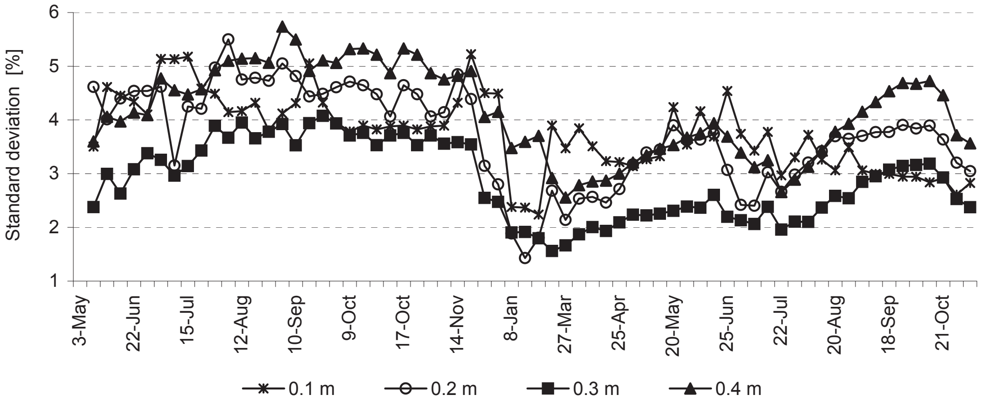

Fig. 2. Seasonal dynamics (2008–2009) of standard deviation of soil moisture in different depths (0.1–0.4 m) expressed in percent of volumetric soil moisture

standard deviation in the course of winter months (from December to March) was left out from the evaluation because it was induced by freezing of soil water, not by water deficit.

The spatial soil moisture variability is also well obvious at Figs. 4–7. The particular top views on investigated plot are created for each depth (0.1–0.4 m) and each figure depicts different date. The Fig. 4 shows spatial soil moisture variability in one day during the driest period in September 2008. We can observe here very wide range of soil moisture values in the depth 0.4 m. On the other hand, closer to the surface, especially in 0.1 m depth, the soil was very dry with no higher spatial differences.

The opposite situation of soil moisture dynamics depicts Fig. 5. At these top views, we can observe the soil moisture variability in our monitored plot during the early spring period after snow melting. In this case variability is the lowest in the depth 0.4 m and reaches higher values closer to the surface. We can also find resembling patterns of soil moisture variability in Fig. 6 which refers to the situation after summer rainfall.

Fig. 7 shows again the beginning of autumn where the soil profile usually reaches the lowest soil moisture content. These top views from September 2009 are quite similar to those which we observed in September 2008. Generally, the year 2008 was much drier, as we can see at the Fig. 1. It also confirms the top views from Fig. 4 and Fig. 7, which represent the driest moment of the two years of monitoring.

In plant production, the information about water availability has much higher value than other growth predictors. The Fig. 8 expresses the mean temporal dynamics of soil available water in whole profile (0–0.45 m). The standard deviation refers to the spatial variability of available water across the investigated plot. The maximal values of the mean available water throughout the whole profile ranged around 70 mm whereas the minimal values decreased to 30 mm.

As we can see also at Fig. 9, the minimal values of available water were measured understandably near the surface. The events of zero water availability were in few cases observed deeper from the surface. The relationship between mean soil water availability and the standard deviation (Fig. 9 and Table 2) is analogical to the relationship of mean soil moisture content and its standard deviation (Fig. 3). The only difference is distinctive in the superficial layer (0–0.15 m) where the correlation of mean values and standard deviation was positive (Table 2). The spatial variability of the soil water availability is also depicted on Fig. 10, where the particular days are chosen.

As we could see above, soil water availability in the soil profile 0–0.45 m ranged from the field capacity to the stress point and sometimes also a little bit lower. The reaction of poplars trees to lack of water which can be easily extracted by the root system is depicted at Fig. 11. There are clearly visible peaks in diurnal patterns of stem diameter increment, which are linked to the peaks of increased soil water availability. Naturally, these sudden increases of the soil water content refer to the

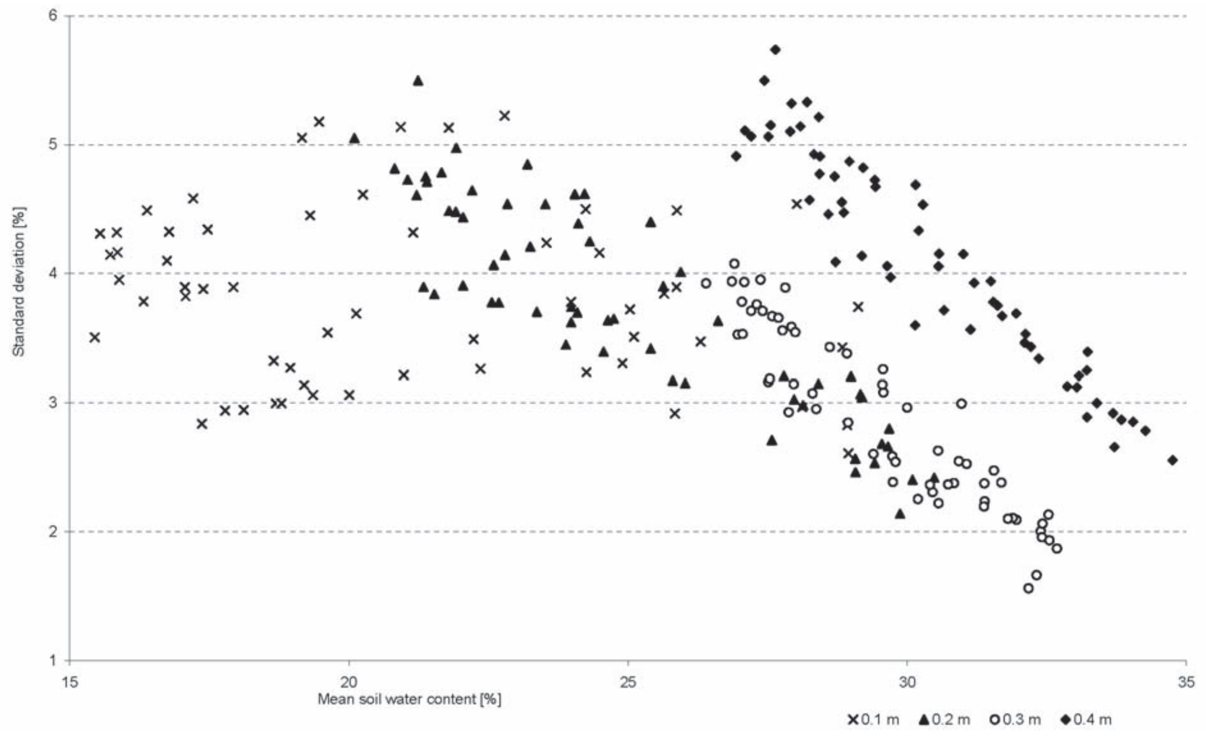

Fig. 3. Standard deviation of soil moisture [%] versus mean soil water volumetric content [%] in different depths

occurrence of precipitation. By omitting these short-term trunk swellings during the day with precipitation in further analyses we can observe that if the available water supply gets roughly around 30 mm, the diurnal rates of stem diameter increment significantly decrease. The relationship between content of available soil water within the whole soil profile (0–0.95 m) and the diurnal increment of stem in diameter is well illustrated at Fig. 12 and the same situation after omission the values from day with precipitation at Fig 13. The correlation coefficients for the particular layer over the whole profile are placed in Table 3.

Table 1. Correlation coefficients describing the relationship between the mean soil moisture content [%] and the standard deviation of soil moisture content [%] in different layers

Soil layer	Correlation coefficients
0–0.15 m	–0.192
0.15–0.25 m	–0.888
0.25–0.35 m	–0.936
0.35–0.45 m	–0.950

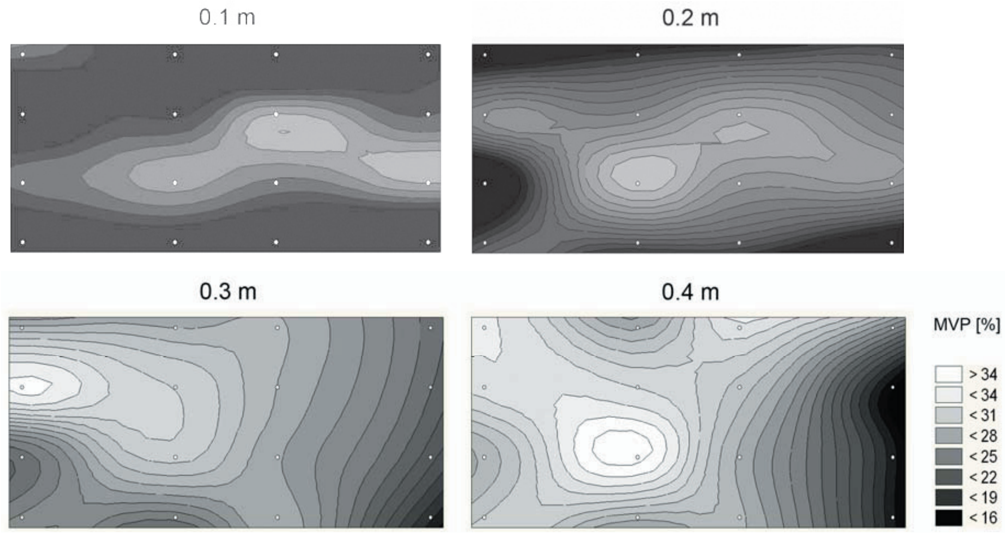

Fig. 4. Spatial patterns of soil moisture content in particular depths during the driest day (6/9/2008). The scale from white to black depicts the range of moisture volumetric percentage (MVP) from the wettest to the driest areas.

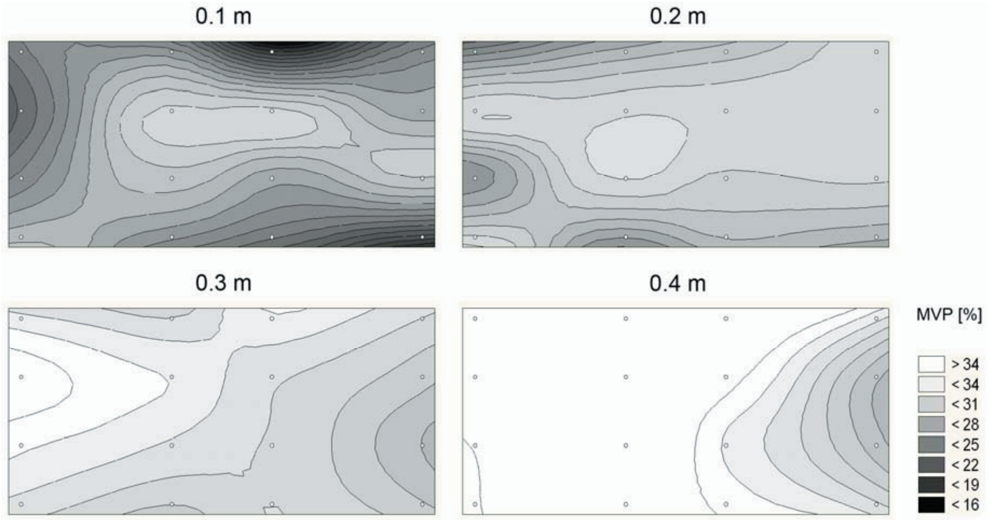

Fig. 5. Spatial patterns of soil moisture content in particular depths during the day after snow melting (27/3/2009). The scale from white to black depicts the range of moisture volumetric percentage (MVP) from the wettest to the driest areas.

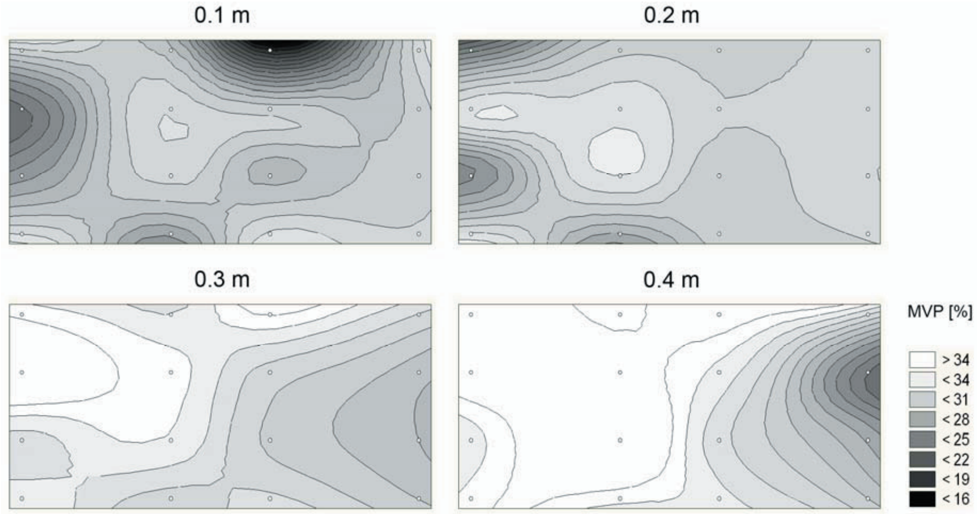

Fig. 6. Spatial patterns of soil moisture content in particular depths during the day after a strong rainfall (2/7/2009). The scale from white to black depicts the range of moisture volumetric percentage (MVP) from the wettest to the driest areas.

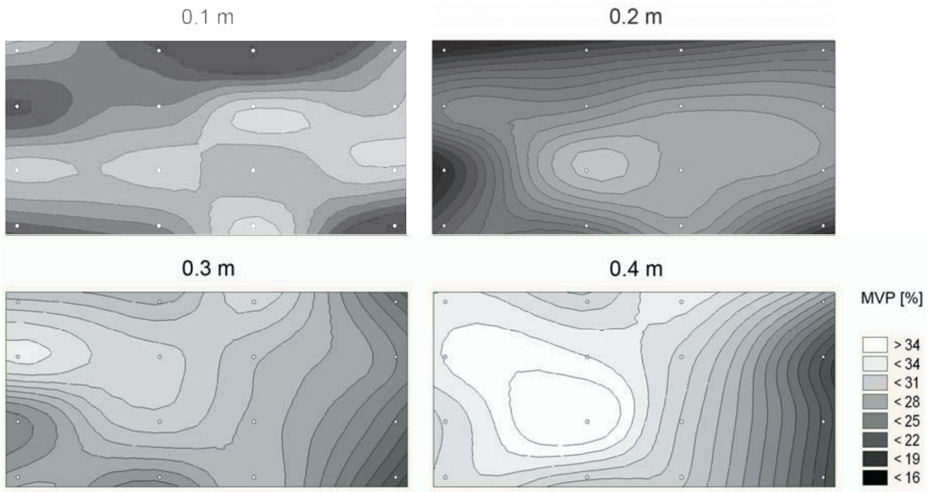

Fig. 7. Spatial patterns of soil moisture content in particular depths within another very dry day (23/9/2009). The scale from white to black depicts the range of moisture volumetric percentage (MVP) from the wettest to the driest areas.

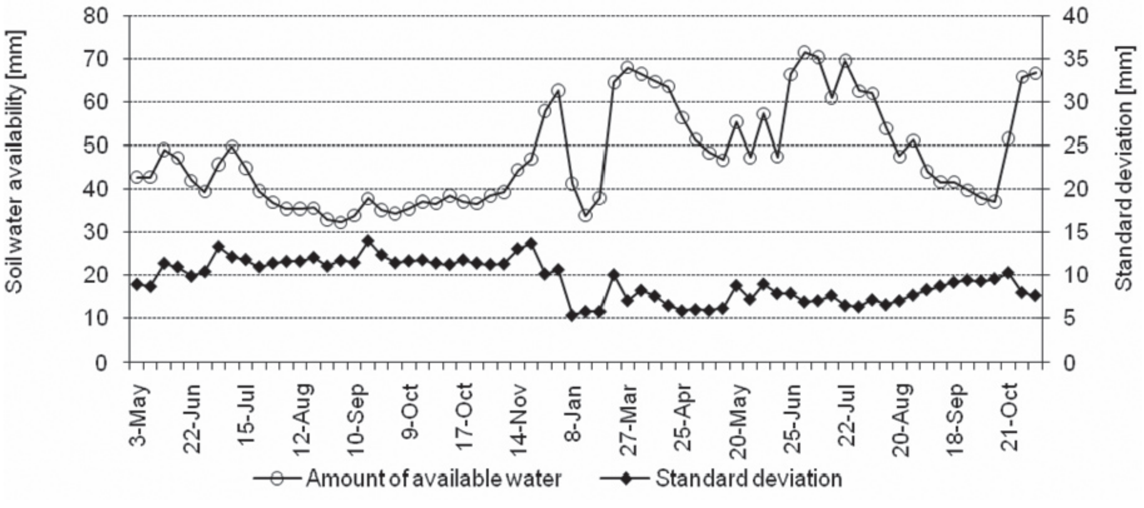

Fig. 8. Seasonal dynamics of average available soil water content in the profile 0–0.45 m measured for all 16 access tubes and its spatial variability expressed as the standard deviation (both in mm of available water)

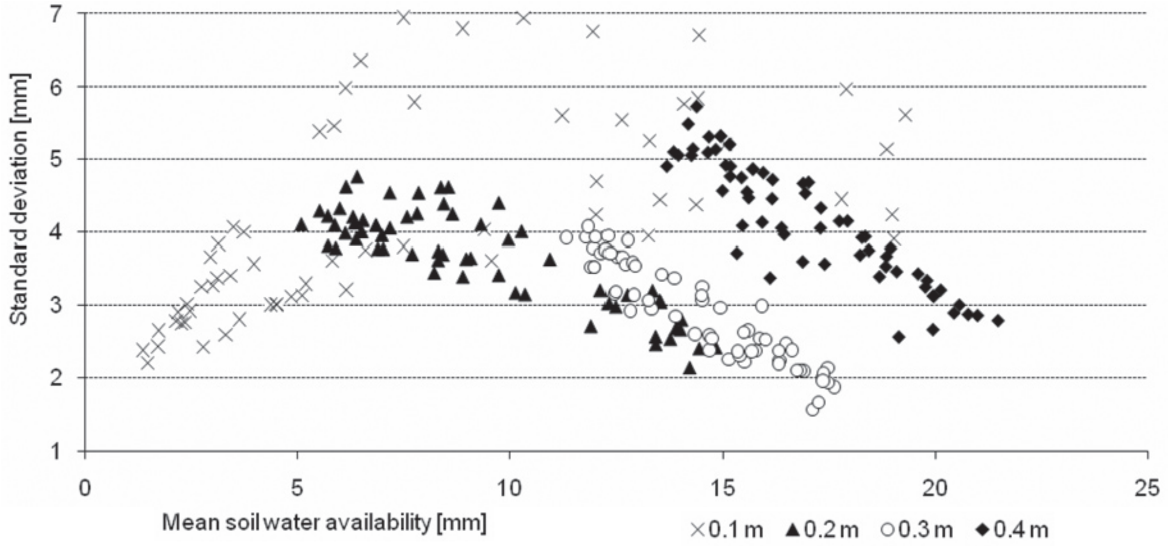

Fig. 9. Standard deviation of soil water availability [mm] versus mean available soil water content [mm] in different depths

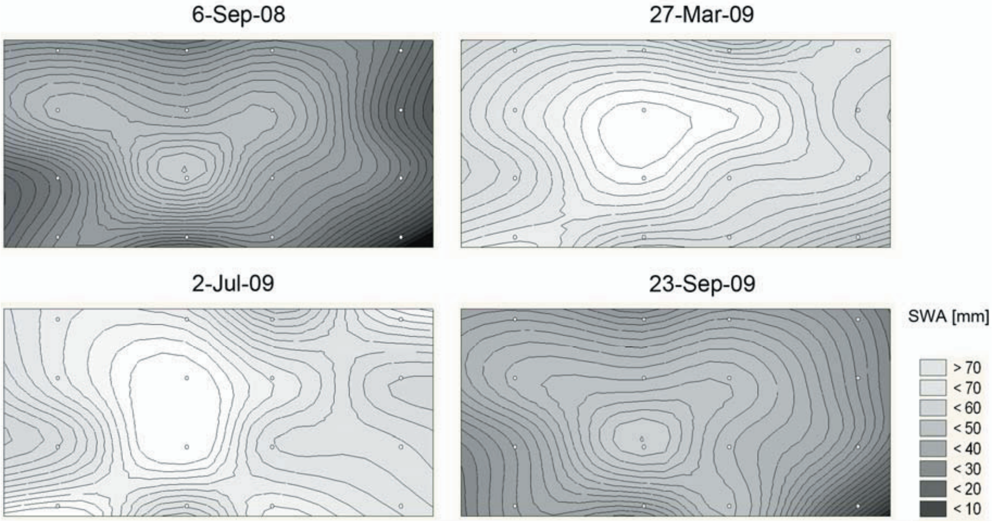

Fig. 10. Spatial patterns of soil water availability (SWA) in the whole profile 0–0.45. Each picture symbolizes a particular day. There are depicted two days when poplars suffered from water stress (6/9/2008 and 23/9/2009) and two days with sufficient available water (27/3/2009 and 2/7/2009). The scale from white to black depicts the range of soil moisture availability [mm] from the wettest to the driest areas.

Table 2. Correlation coefficients describing the relationship between the mean soil water availability [mm] and its standard deviation [mm] in different layers

Soil layer	Correlation coefficients
0–0.15 m	0.630
0.15– 0.25 m	–0.851
0.25– 0.35 m	–0.936
0.35–0.45 m	–0.933
0–0.45 m	–0.653

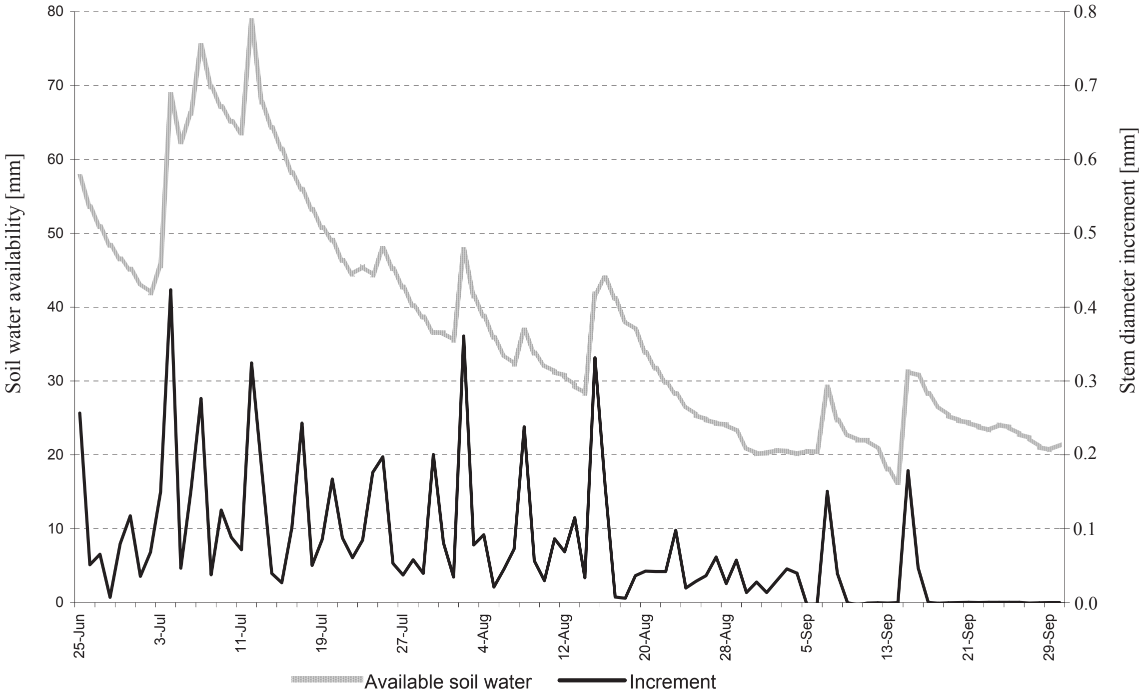

Fig. 11. Available soil water in the layer 0–0.45 m, and diurnal intensity of stem diameter increment during the summer and the beginning of autumn 2008

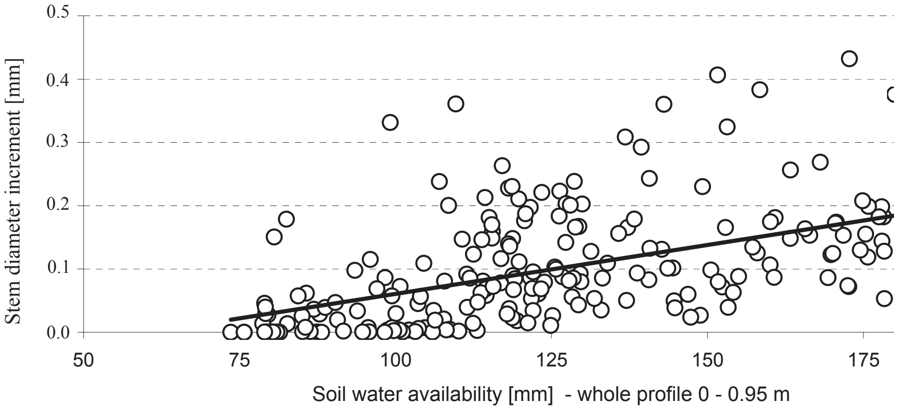

Fig. 12. Relationship between the amounts of available soil water in the layer 0–0.95 m and the diurnal stem diameter icrement

Table 3. Correlation coefficients describing the relationship between stem diameter increment [mm] and the soil water availability [mm] in different layers

Soil layer	Correlation coefficients	
	Days with rain included	Days with rain excluded
0–0.15 m	0.467	0.579
0.15–0.25 m	0.525	0.666
0.25–0.35 m	0.550	0.708
0.35–0.45 m	0.551	0.711
0.45–0.55 m	0.550	0.713
0.55–0.65 m	0.548	0.715
0.65–0.75 m	0.544	0.715
0.75–0.85 m	0.536	0.714
0.85–0.95 m	0.522	0.708
0–0.95 m	0.522	0.698

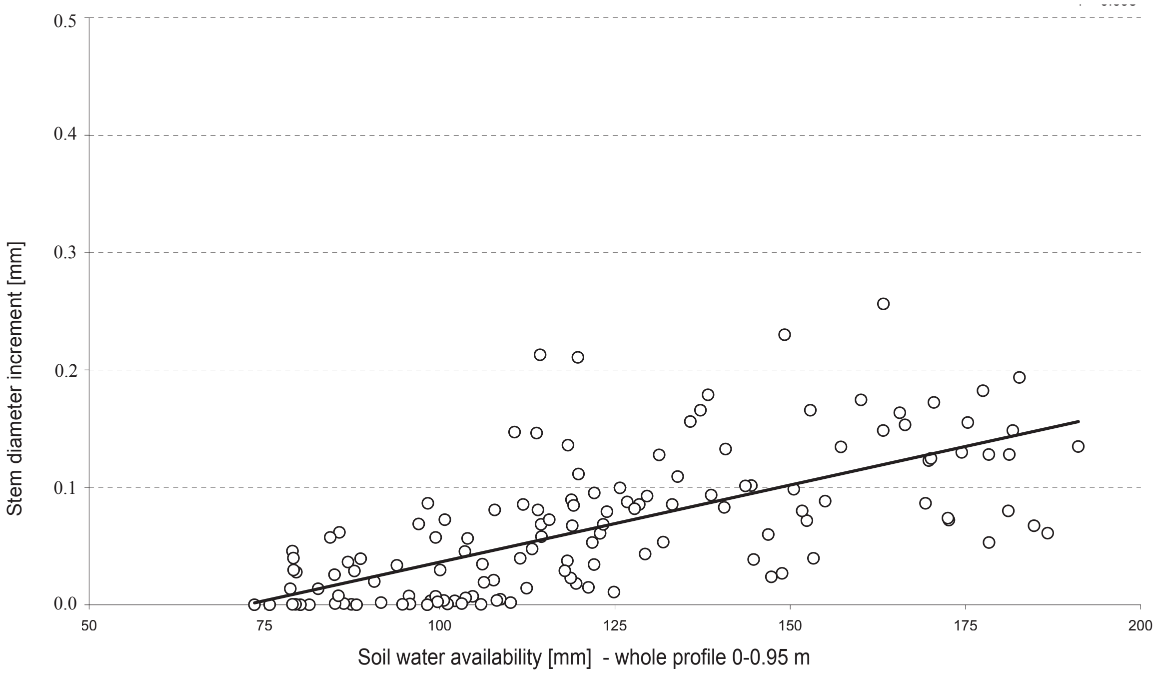

Fig. 13. Relationship between the amounts of available soil water in the layer 0–0.95 m and the diurnal stem diameter increment. The days with occurrence of precipitation were excluded in this correlation.

Discussion

The seasonal dynamics of soil moisture was typical with a large supply of available water at the beginning of spring after snow melting. The second period of the highest soil moisture values appears usually after summer rainfalls, especially in June and July which are the two months with the highest amounts of precipitation in the conditions of the Czech Republic. By contrast, shortage of soil water content was recorded at the end of summer in both of the monitored years. Such decrease of soil moisture occurred due to low precipitation and high evapotranspiration rates during this period. The soil moisture temporal dynamics was obviously depth dependent and was also more pronounced closer to the soil surface, where soil is subjected to the root water uptake and rainfall events. Indeed, the widest range (from the field capacity to the wilting point) of soil moisture values were observed in the upper layers 0–15 and 15–25. Similar results had been already observed by Loague (1992), Hupet and Vanclooster (2002). The temporal dynamics in the intermediate layers is clearly more attenuated. Nevertheless, these layers become progressively drier in response to the root water uptake combined with the upward flux. Within the deeper layers, the temporal persistence of some dry and wet zones within the field remains high. The persistence of drier zones can be explained by the sandy material from the disintegrating gneiss underlying the loamy soil. Naturally, it is well known that the thickness of the loamy layer is quite variable within the region but also within fields (Dudal, 1953). It is therefore assumed that the dry sampling locations are situated where the loamy soil is shallow, leading to measuring the soil moisture within the transition zone between the loamy soil and the sandy material. Visual observations of the soil profile during the gravimetric sampling confirm this hypothesis. On the other hand, some sampling locations are very wet in depth 0.3 and 0.4 m and it is hypothesised that a fine textured layer at this location leads locally to a perched water table.

The soil moisture data set collected in this study allows investigation of the relationship between the field-scale means and variance of soil moisture content over time. If such relationship exists, it can be of great significance, for example to optimise the number of samples required to estimate the mean value within a specified limit of error. Our results demonstrate that the spatial variability linearly decreases with the increasing mean soil moisture values. This negative correlation is consistent with the previous findings of e.g. Famiglietti et al. (1999) or Hupet and Vanclooster (2002). Nevertheless, observed results are in contrast with other previous investigations (e.g. Hills and Reynolds, 1969; Hennenger et al., 1976; Famiglietti et al., 1998). However, most of the disagreeing studies were conducted on experimental sites with much more pronounced topographic features. The widest range of variability during the dry period was observed in the layer 0.35–0.45 m. We assume on the grounds of the visual assessment of soil profile during the gravimetric sampling that the higher variability of soil moisture in deeper layers appears just because there are places with occurrence of sandy material mentioned above. The soil water from these fields can drain to the deeper layers and thus the soil get dry. During the wettest days was the layer 0.35–0.45 much more homogenous and also reached the highest soil water content. With an adoption of the term soil available water, which is the water up the wilting point, and providing that the majority of the roots are located in the profile 0–0.45 m, we can calculate how much water in this layer could be used by the plants. Generally, the amount of the available soil water fluctuated between field capacity and the stress point. Our results showed there was enough available water for the poplars to grow across the whole investigated area almost during the whole season. Nevertheless, in the driest period (the end of summer 2008 and 2009) the soil water availability decreased under the level of stress point and in some rare cases even near the wilting point at some places of the investigated plot (the places where the sandy soil was observed). Note there is quite significant positive correlation between soil water availability and the spatial variability expressed as the standard deviation, which is in the opposite with the same correlation of soil moisture and its spatial variability. The main explanation is that when the soil water availability decrease under the zero level, the whole plot seems to be very homogenous from this point of view whereas the soil moisture values are different. On the other hand, when the upper soil profile is saturated with water, the moisture availability is spatial homogenous only in the moment of the saturation and some while after. Because of the draining to the deeper layers and due to evapotranspiration, the spatial variability raise very soon.

If we evaluate the reaction of poplars to the water stress, it seems to be very suitable to observe the stem diameter increment and the available water content at the same time. It is well known that trees can tolerate longer periods of low soil water content than herbaceous plants through specialized long- and short-term physiological, phenological, anatomical, and morphological adaptations (Ludlow, 1989), such as growth reduction, stomatal closure, and osmotic adjustment (Hsiao and Acevedo, 1974). Poplars typically respond to water stress by closing stomata (Schulte et al., 1987; Bassman and Zwier, 1991; Dickmann and Pregitzer, 1992), although considerable genotypic variation can occur. Our results showed that if there was less than approximately 100 mm of available water in the whole profile (0–0.95 m), the stem volume stopped to increase. At this time, we have also observed that this clone shows a distinct tendency to abscise leaves in the lower crown as water stress increases. We can define this value of available water content as so-called stress (refill) point, which is described as the soil water content below which plant growth is measurably decreased (Campbell and Campbell, 1982). With the assumption, that the maximal available-water-holding capacity of the whole profile was determined as 194 mm, we can roughly estimate that the stress point of poplar clone J-105 is near the half of the range between the wilting point and the field capacity, which confirms the generally used conservative value of stress point as 0.5* (PAW) – plant available water (e.g. Charlesworth and Stirzaker, 2008).

Generally, growth is the biological phenomenon of increase in size with time. Growth involves the formation, differentiation and expansion of new cells, tissues or organs. The sudden increase in tree diameter often observed after rain is not due to growth but reflects the saturation of shrunk xylem and other stem tissues with water after some drier period (Offenthaler et al., 2001; Herzog et al., 1995). That’s why we found stronger correlation between available soil water content and the stem diameter increment after we had omitted the day with the occurrence of precipitation. The highest correlation coefficients were recorded in the profile 0.45–0.85 m. But it doesn´t have to only mean, that in this depth is the strongest linkage between the soil water availability and stem increment and thus that there is most of the root system. It can also represent a time delay which could be theoretically the same for percolation in this depths and the reaction of growth on changed soil moisture in upper layers. Of course, the biomass yields are not influenced only by the water deficit, but very important role play solar radiation, temperature, available nutrients, etc. (Cannell et al., 1987; Han et al., 2003; Lindroth and Båth, 1999; Schneider et al., 2001). As an illustrative example, we provided a simple approach to the relation between solar radiation and stem biomass increment in Table 4. Naturally, higher solar interception leads to a certain extent, to higher photosynthetic activity, and thus to higher yields of biomass.

Table 4. The basic statistics values of stem diameter increment [mm] for different ranges of global radiation [MJ] reveal the relationship between the radiation and biomass increment.

Daily totals of global radiation [MJ]	The basic statistics of daily stem diameter increment [mm]				
	Standard deviation	*Average*	*Median*	*Maximum*	*Minimum*
10–15	0.068	0.048	0.004	0.230	–0.002
15–20	0.050	0.041	0.021	0.166	–0.003
20–25	0.054	0.083	0.081	0.256	0.000
25–30	0.055	0.093	0.072	0.194	0.034

The results of this study seem to be as a suitable material for creating and calibrating a dynamics crop model applicable for SRC. In further studies, other factors like solar radiation, temperature, transpiration, nutrients availability, dynamics of leaf area index and phenology have to be involved to the broad access of modelling. After necessary parameterization and validation, the utilization of such tool could contribute to optimize the management strategies of growing SRC and also to choose the potential areas suitable for SRC.

Acknowledgement

The presented study was supported by In-house Grant Agency at MUAF in Brno no. IGA 14/2009, In-house Grant Agency at Mendel University in Brno no. TP 11/2010 and by the Research plan no. MSM 6215648905 "Biological and technological aspects of the sustainability of controlled ecosystems and their adaptability to climate change" financed by the Ministry of Education, Youth and Sports of the Czech Republic.

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Dostupnost vody v porostu rychle rostoucích dřevin (*Populus nigra* × *P. maximowiczii*) v podmínkach Českomoravské vrchoviny

Souhrn

Cílem této studie je přispět k diskuzi o efektivitě produkce rychle rostoucích dřevin (RRD) na vybraných stanovištích a zároveň na základě přesných bioklimatologických měření definovat a modelovat ideální podmínky pro jejich pěstování. Předkládaná publikace se zabývá především vztahy mezi přírůsty biomasy a dostupností vody, jakožto limitního faktoru. Dále obecně pojednává o dynamice a prostorové variabilitě vlhkostního režimu půdy v porostu RRD. Pozorování a měření probíhaly na topolové plantáži nacházející se na lokalitě Domanínek (Česká republika, 49° 32' s. š. a 16° 15' v. d., 530 m n. m.) v katastrálním území města Bystřice nad Pernštejnem. Jedná se o monokulturní plantáž v ČR v současné době nejpoužívanějšího rychle rostoucího topolového klonu J-105 (*P. nigra* × *P. maximowiczii*) o celkové rozloze 4 ha. Ačkoli zdejší klimatické podmínky pro pěstování topolových porostů RRD dosahují téměř limitních hodnot, stanoviště je zcela produkce schopné a to zejména díky hlubokému půdnímu profilu.

Výsledky týkající se dynamiky půdní vlhkosti a její prostorové variability potvrzují, že zásoba vody v půdě v průběhu vegetační sezóny postupně klesá. K nasycení dochází obvykle brzy na jaře po tání sněhu a po intenzivních letních deštích. V těchto obdobích je rovněž prostorová variabilita půdní vlhkosti nejnižší. Po déletrvajících přísušcích, které byly zaznamenány v obou sledovaných letech (2008 a 2009) na konci léta, dochází ke značnému poklesu půdní vláhy až pod bod snížené dostupnosti. Tyto nejsušší periody byly naopak charakteristické nejvyšší prostorovou variabilitou. V obdobích sucha byl rovněž pozorován průkazný pokles u přírůstů na kmenech a byl tak definován bod snížené dostupnosti pro klon J-105 nacházející se přibližně v polovině mezi bodem vadnutí a polní kapacitou. Získané vztahy a výsledky mohou sloužit jako podklady pro tvorbu nových dynamických růstových modelů aplikovatelných pro RRD, ale i pro parametrizaci a validaci modelů stávajících. V dalších studiích je nutné zohlednit vliv dalších faktorů na tvorbu a dynamiku přírůstů biomasy. Jedná se především o solární radiaci, teplotu, dostupnost živin v půdě, dynamiku vývoje listové plochy a fenologii porostu. Po nezbytné parametrizaci a prověření vypovídací schopnosti modelů by bylo s jejich využitím možno přispět k optimalizaci pěstování RRD, k selekci nových stanovišť a odhadu možných výnosů.

Received January 7, 2010
Accepted April 4, 2010