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TRANSPIRATION RATE OF SCOTS PINE TREES ON VERY OLIGOTROPHIC SOILS OF NORMAL MOISTURE IN RELATION TO DIFFERENT METEOROLOGICAL CONDITION

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Continuous monitoring of the tree ring formation and transpiration throughout the year is crucial for understanding the tree reaction to changes in meteorology, and evaluating its adaptiveness to recent environmental changes. Data were collected from four *Pinus sylvestris* L. trees which sapflow was measured by the heat wave propagation method using SFM1 sensors (ICT International, Australia) and annual tree stem increment by electronic dendrometer DRL26. Investigation was performed in middle age pine stand on very oligotrophic soil. Meteorological data revealed that 2019 was the year of drought. In this year pine transpiration rate and volume increment were the lowest. However, water was used most efficiently, which means that pines needed less water to produce 1 cm^3 of wood. 2020 was characterized as a year of recovery of moisture regime, when during vegetation precipitation increased up to long term value and the mean air temperature was the lowest. Annaul volume increment of pine trees in this year was the biggest, transpiration rate the highest, but WUE was the smallest, indicating that pine used more water to produce 1 cm^3 of wood. Obtained data on WUE during different growing season revealed that Scots pine trees are well adapted to recent meteorological condition. Increase in tree diameter reduced values of Scots pine WUE, what means that bigger pine trees used significantly less water to produce 1 cm^3 of wood.

Keywords: tree sapflow, volume increment, water use efficiency, adaptive capacity

INTRODUCTION

Questions about anthropogenic effects on the environment, through manipulation of the vegetation, have become increasingly topical in recent decades. The partitioning of absorbed radiation into sensible and latent heat at the Earth's surface is a key process for the climate (Sellers et al., 1997; Higgins and Schneider, 2005). Climate change with increasing air temperature by intensity of 3 - 6 °C over 100 years may affect forest sustainability and adaptive capacity to unfavorable environmental conditions such as drought, frost and heat (Lévesque et al., 2014) as well as air pollution by acidifying compounds (Augustaitis et al., 2007a, 2010a, 2010b, 2011; Holmberg et al., 2013, Forsius et al., 2021) and tropospheric ozone (Paoletti et al., 2007, Serengyl et al, 2011, Sicard et al., 2016; Vuorenmaa et al., 2017). Such changes could affect also trees resistance to pest damage (Augustaitis, 2007). Long-term analysis of meteorological data for a gradient from the coastal to eastern inner Lithuania revealed an increase in annual air temperature and precipitation and rising variation in monthly patterns during the period 1981-2020 compared to 1950-1980 (Augustaitis *et al*., 2018, 2021). The lack of atmospheric humidity is predicted to reinforce negative effect of climate warming in southern and central parts of Europe, meanwhile in northeastern part of Europe, including Lithuania gradual increase in precipitation amount should mitigate this negative effect of climate changes increasing tree increment (Augustaitis et al., 2015, 2018).

The state of knowledge revealed that the widely distributed pioneer species *P. sylvestris* is known as being tolerant to moderate drought effect. Its drought sensitivity depends on site related factors especially on relief, topography and soil characteristics such as rooting and water holding capacity of soils (Levesque et al., 2014). Therefore, the reactions of this considered tree species to extreme meteorological events under different growth conditions differed significantly due to their different strategies (McDowell 2008; Augustaitis et al., 2018; Marozas et al., 2019) when surviving first of all heat and drought episodes (Lévesque et al., 2014; Augustaitis 2021) what quite well indicates their needles spectral reflectance (Masaitis et al., 2013, 2014). This finding well agreed with results obtained on annual scale which indicated that meteorology explained variation in annual pine tree ring width variation more significantly than acidifying compounds (Augustaitis et al., 2007b, 2015, 2018; Juknys et al., 2014).

Continuous monitoring of tree ring formation throughout the year together with the stem sapflow intensity is crucial for the understanding of tree reaction to changes in environmental conditions, such as temperature, soil water content and rainfall. This investigation can be performed by using sapflow equipment (Baumgarten et al., 2019) and automatic dendrometers (Deslauriers et al., 2007; Augustaitis 2021). These equipments provide time series composed of diurnal rhythms of water storage depletion and replenishment which result in general tree ring formation.

Tree transpiration is the major pathway for both water and energy leaving the forest ecosystem. Measurement of transpiration provides access to the canopy conductance of the forest, a key parameter in models of water- and carbon-exchange (Collins and Avissar, 1994), since the water and carbon fluxes are strongly linked by their common passage through the stomata (Morén et al., 2001). The sapflow technique (Swanson, 1994) is very useful for obtaining the total water use efficiency (WUE) of a single tree. Sapflow is commonly scaled up to stand level and considered as representing transpiration. A problem with this approach is that, because of the capacitance of the trunk ant branches, sapflow lags somewhat behind transpiration (Granier and Loustau, 1994; Köstner et al., 1996).

To solve the problem which deals with resistance of Scots pine trees during the unfovourable environmental condition, pine tree water use efficiency on the purest for tree growth site condition was analised to the aim to establish their adaptive capacity to recent meteorological condition.

MATERIALS AND METHODS

Location and stand characteristics. The main research objectives are prevailling in Lithuanian forest Scots pine (*Pinus sylvestris* L.) trees growing on seaside part of Lithuania in the territory of Nida forest enterprises on poorest for tree growth wind made sandy soils (1 fig).

Figure 1. The location of the monitored Scot pie trees

Forest type. Forest site: Oligotrophic mineral soil Forest Site. Soil type is *haplic arenosol* (table 1), water table is deeper than 2 m. Soil water potential at the depth of 40 cm is higher than at the depth of 10 and 20 cm. Scots pine dominate in the first stand layer. Herbaceous vegetation – *Vaccinium vitis-idae, Melampyrum pratense, Pleurozium schreberi, Hylocomnium splenden, Dicranum polysetum.*

Meteorological condition. Meteorological data obtained from Nida meteorological station revealed that during the last 40 year long period mean air temperature increased by 0.05 °C per year and this trend was statistical significant ($p<0.05$). Precipitation amount during this period also increased, but not significant and made 1.35 mm per year. Significant increase in air temperature especialy in April, June, August, September and November resulted in significant change in annual air temperature (3 fig). Reduction in amount of precipitation in June and September following by increase in amount of precipitation in February, July, August and October resulted in insignificant changes of annual amount of precipitation.

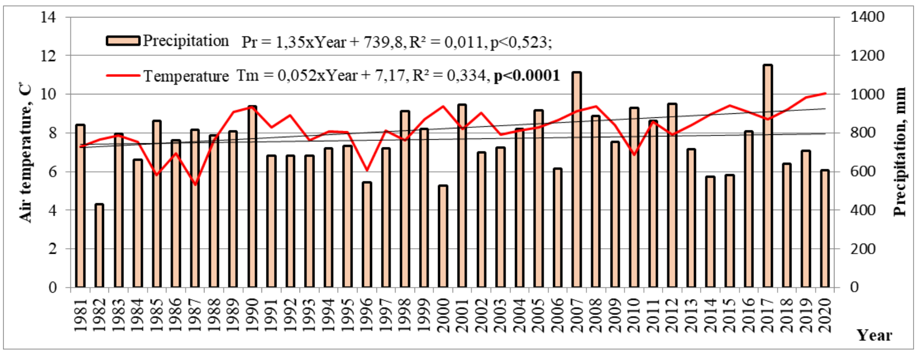

Figure 2. Precipitation and air temperature 1981-2020.

Precipitation amount and air temperature was analised for few periods during 2018-2020:

- The annual period - lasts 12 months. Begins in September, ends in August;
- The vegetation period **-** lasts 5 months. Begins in April, ends in August;
- The dormant period **-** last 7 months. Begins in September, ends in March.

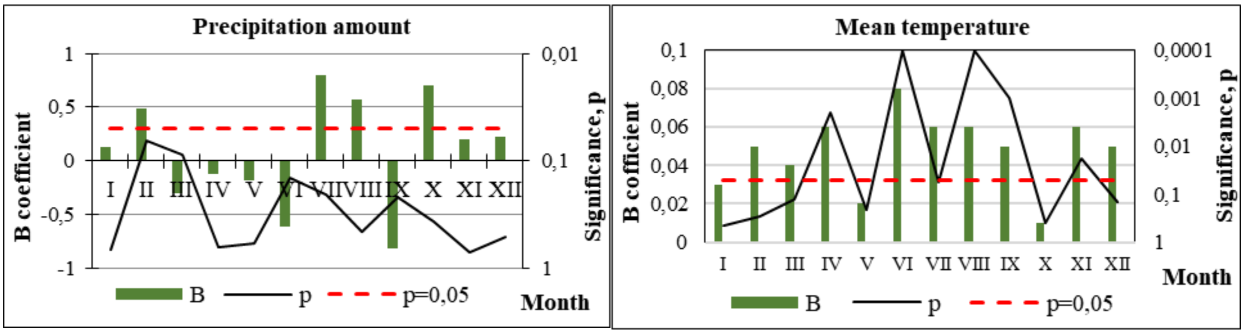

Figure 3. Slope of changes in monthly precipitation amount and mean air temperature (B coefficient of linear regression) and its significance (p)

Comparison of meteorological data during these periods allowed to identify the most humid and hot year when pine trees survived stress and the most acceptable for growth year, when pine trees regenerated.

Heat-pulse method HRM. Xylem sap flow measurements were conducted by applying the heat ratio method (Burgess et al., 2001) using sap flow meter (SFM1) from ICT International (Australia). Sap flow sensors were installed at approximately 120 cm stem height and sheltered with aluminium foil caps. Bark thickness was measured for each sample tree by using a bark depth gauge, sensor needles measuring at two different depths were inserted into the sapwood with a bark depth of 10 mm (bark removed or spacer set).

Principle of measurement – determination of temperature differences, use of cylindrical thermocouples and heater, probes inserted into the tree xylem

- uses a short pulse of heat as a tracer
- 3 probes are inserted radially into the tree sapwood middle probe generates a heat pulse and the temperature changes are measured by the other 2 probes.

The sensors measure heat pulse velocity by obtaining the ratio of downstream to upstream sapwood temperature after a heat pulse (4 fig.). Transpiration rate was analyzed at four different time periods which are presented in table 1.

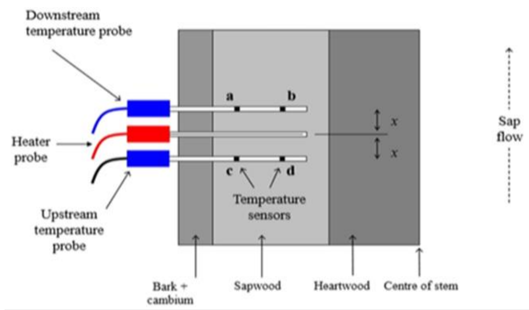

Figure 4. Heat-pulse method HRM (Burgess et al. 2001)

Table 1. Transpiration periods 2018-2020

	SF1	**SF2**	**SF3**	**SF4**
Period	From the begining of growth to he first (actual) end of growth)	From the begining of growth to the second (final) end of growth	From the begining of transpiration to the end of transpiration	from the beginning of transpiration to the beginning of growth,
2018	**Start:** April 29 **End:** August 15	**Start:** April 29 **End:** September 26	**Start:** March 11 **End:** November 5	**Start:** March 11 **End:** April 29
2019	**Start:** April 24 **End:** August 16	**Start:** April 24 **End:** September 27	***Start:** February 10 **End:** December 21	**Start:** February 10 **End:** April 24
2020	**Start:** April 21 **End:** August 6	**Start:** April 21 **End:** September 17	**Start:** February 2 **End:** December 2	**Start:** February 2 **End:** April 21

*2019-2020 stood out as a problematic year due to the warm winter effect.

Tree sesonal growth

Radial stem annual growth at a height of 1.3 m was measured with manual and high-resolution dendrometers (DRL26, EMS Brno) with an accuracy of ± 0.1 mm and 0.001 mm, respectively. The annual increment of the tree stem perimeter using was determined according to the formula:

$$ZP = P2 - P1, \quad (1)$$

P1 is the perimeter of the tree at the beginning of the vegetation period, mm
P2 - tree perimeter at the end of the vegetation period, mm.

Diameter of monitored pine trees varied between 19 and 29 cm at breast hight, height between 15-16 m and volume between 0.2-0.4 m3.

RESULTS

Meteorological condition and soil moisture during investigated period (2018-2020)

At the Nida forest enterprise mean annual air temperature in 2020 reached 10.0°C indicating one of the warmest years over the whole period of investigation, and dormant air temperature reached 6.7°C indicating the warmest dormant periods over the whole year of investigation. Data on dormant, vegetation and annual air temperature and precipitation between 2018-2020 revealed that in 2018 precipitation amount was the biggest and air temperature was the lowest in dormant period, but during the vegetation period air temperature and precipitation reached the highest values (Fig. 5). 2019 was evaluated as a year of drought during vegetation period. Mean annual precipitation decreased to 626 mm (precipitation in 2018 – 996 mm; 2020 – 715 mm) while during vegetation up to 190 mm. In 2020, precipitation amount increased up to long term value and moisture regime recovered.

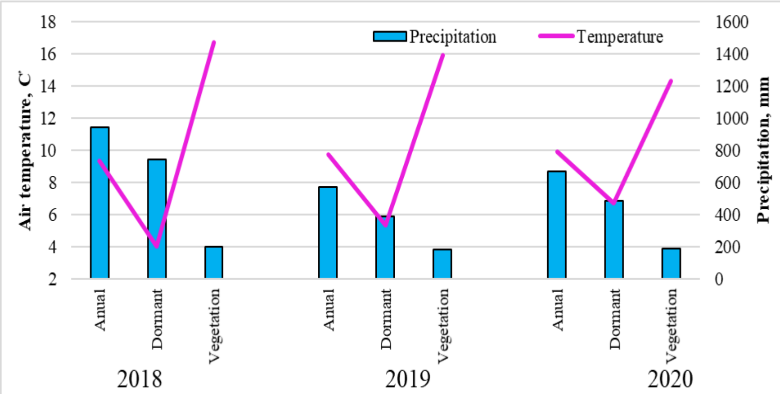

Figure 5. Average air temperature and precipitation for different period (annual, domant, vegetation) in 2018-2020.

2019 June was characterized as month with the highest mean air temperature and lowest precipitation amount (Table 2). 2020 June and July were characterized as months with the biggest amount of the precipitation i.e. moisture regime recovered.

Table 2. Average monthly air temperature and precipitation for growing season in 2018-2020 from September to August

T, ˚C	IX	X	XI	XII	I	II	III	IV	V	VI	VII	VIII
2018	14,7	9,9	5,8	3,3	-0,2	-4,3	-1,4	8,3	16,5	17,6	20,4	20,9
2019	16,4	10,5	4,6	1,1	-1,2	2,0	3,7	9,0	12,1	**20,4**	18,1	19,7
2020	15,1	10,9	5,9	2,3	4,5	4,0	4,4	7,3	10,5	18,8	15,0	20,0
P, mm	IX	X	XI	XII	I	II	III	IV	V	VI	VII	VIII
2018	151	277	108	91	78	34	19	39	33	31	61	74
2019	69	99	**18**	82	80	38	59	0	62	**28**	**51**	**40**
2020	77	125	84	60	72	63	42	6	21	46	61	58

Transpiration rate

Meteorology was a key factor resulting in the variations in transpiration intensity. Hight air temperature and precipitation stimulated transpiration intensity in 2018 and 2020 while low precipitation reduced transpiration intensity in 2019. In 2019-2020 pine transpired all year, so, in this period it is important to emphasize that transpiration does not begin but intensified in February and started to reduc in December (Fig. 6)

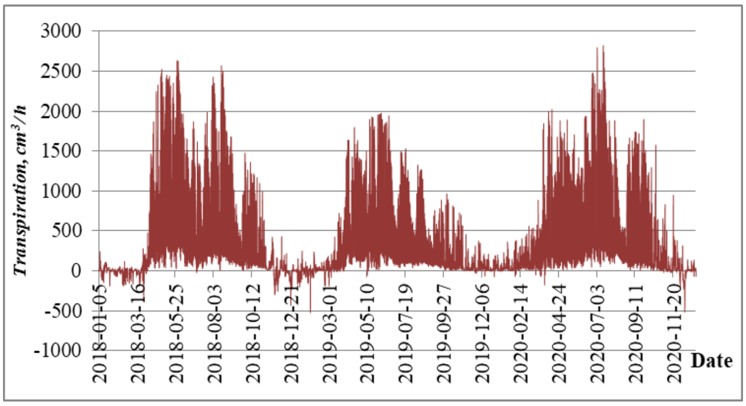

Figure 6. Pine transpiration of monitored pine trees in 2018-2020

Whole transpiration rate from the beginning up to the end was detected adding SF3 value with SF4. Obtained data revealed that whole transpiration rate in 2019 was the lowest and made 2879 l per year, while the highest its value was registered in 2020, when it made 3622 l per year. Analysing data on vegetation period obtained data indicated that the lowest transpiration rtate was detected also in 2019, while the most intensive transpiration rate was in 2018. The most intensive transpiration before the beginning of growth was registered in spring of 2020. These variations in transpiration rate could have had significant effect on tree water use efficiency.

Table 3. Transpiration of monitored pine trees in 2018-2020

Year	Period	Pine_1	Pine_2	Pine_3	Pine_4	Average	Total number of hours	Total air temperature, ° C	Total precipitation, mm
2018	SF1, l	1731.2	1531.0	2768.9		2010	2616	48899.4	186
	SF2, l	2215.0	1993.5	3519.5		2576	3624	67905.6	273
	SF3, l	2559,3	2279.8	4221.5		3020	5760	82577.4	423.1
	SF4, l	239.1	202.5	534.6		325	1200	5906.3	53.8
2019	SF1, l	1401,9	788.2	2478.1	1667,0	1556	2761	46716.8	176
	SF2, l	1591.6	923.1	3051.9	1922,9	1856	3768	64150.8	222
	SF3, l	2012.9	1203.5	4120.3	2310,0	2446	7560	87539.9	593,8
	SF4, l	327.3	230.4	742.9	292,7	434	1776	8484.8	75.2
2020	SF1, l	1509.8	1184.9	2643.5	2439,3	1779	2592	39658.4	138
	SF2, l	2033.3	1673.9	3705.8	3240,9	2471	3601	58541.8	208
	SF3, l	2460.2	2082.4	4827.7	3909,4	3123	7320	86816.1	485.7
	SF4, l	328.9	319.1	849.1	530,5	499	1920	9293.3	104.2

Trees annual increment

Pine began to grow in April when air temperature reached 7-8°C˚, and ended first, when air temperature was about 19°C˚ (first - actual end in August) and second, when air temperature decreased up to 10 °C˚ (second - final end of growth in October). Pine trees demonstrated the highest increment in moisture regime recovery year, i.e. in 2020. Drought was a key factor resulting in the decrease increment in pine in 2019 (7 fig).

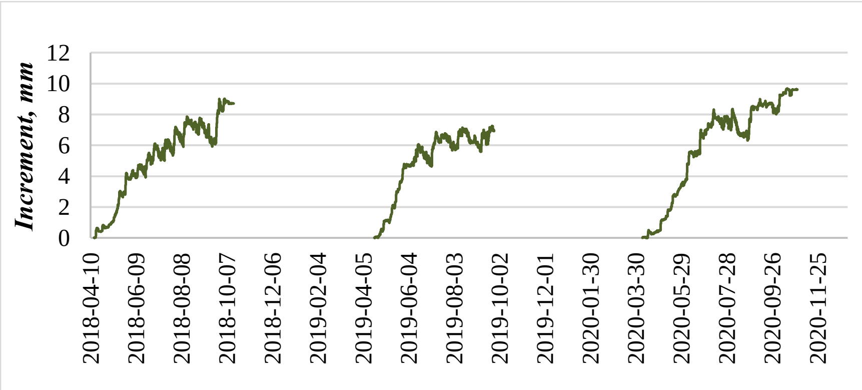

Figure 7. Pines increment 2018-2021

Data on annual volume increment of Scots pine between 2018-2020 revealed that meteorological conditions significantly resulted in variation of tree volume increment. The highest increment was in the year with a lot of precipitation and heat. The drought resulted in the lowest value of annuam stem increment in 2019 (Table 4).

Table 4. Annual volume increment of monitored trees in 2018-2021

	2018				
	Pine_1	**Pine_2**	**Pine_3**	**Pine_4**	**Average**
SF1, cm^3/year	5822.4		5785.9		**5804.2**
SF2 cm^3/year	5989.8		5849.8		**5919.8**
	2019				
SF1, cm^3/year	6312.9	2650.1	6246.8	6011.5	**5305.3**
SF2 cm^3/year	6092.6	2531.5	6485.9	6025.8	**5283.9**
	2020				
SF1, cm^3/year	6331.4	3450.0	6251.4	7179.9	**5803.2**
SF2 cm^3/year	6815.5	3981.6	7215.8	8009.2	**6505.5**

WUE and its evaluation in 2018-2020

Obtained data on water use efficiency shows how many liters of water a tree needs to produce 1 cm^3 of wood. Meteorological condition was also key factor resulting significantly in the value of WUE. In 2018, pine used significantly more water to produce 1 cm^3 of wood than in 2019. WUE of Scot pine was the highest in the driest year (2019), on very oligotrophic soils of normal moisture, indicating their proper adaptation to recent meteorological conditions in a hemi-boreal forest (Table 5). Increase in tree diameter reduced values of Scots pine WUE, what means that bigger pine trees used significantly less water to produce 1 cm^3 of wood.

Table 5. Watter use efficiency (l/ cm^3) during different periods of tree ring formation

	D1.3, mm	WUE_1	WUE_2	WUE_1	WUE_2	WUE_1	WUE_2
		2018		2019		2020	
Pine_1	292	0.30	0.37	0.22	0.26	0.24	0.3
Pine_2	191			0.30	0.36	0.34	0.42
Pine_3	209	0.48	0.6	0.40	0.47	0.42	0.51
Pine_4	273			0.28	0.32	0.34	0.40
Average	241	0.39	0.485	0.3	0.35	0.34	0.41

Note: WUE_1 is the water use efficiency from the biginning of growth to the first end of growth (in August) (SF1), WUE_2 is water use efficiency from the beginning of growth to the total end of growth (in October) (SF2).

CONCLUSIONS

1. Drought (2019) reduced growth and transpiration rates of Scots pine trees growing on very oligotrophic soils of normal moisture, but water use efficiency remained the highest, what means that during the drought, pine tree needed less water to produce 1 cm^3 of wood. Increase in tree parameters increase in pine tree water use efficiency.
2. In the year with normal precipitation amount (2020), pine volume increment recovered and reached the highest values as well as transpiration intensity rate, but the water use efficiency reduce to the lowest values. Increase in tree parameters reduced pine tree water use efficiency during favorable for tree growth period.
3. Obtained data on WUE during different growing season revealed that Scots pine trees are well adapted to recent meteorological condition.

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