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THE GROWTH RING STRUCTURE EFFECT ON MOISTURE CONTENT IN GREEN WOOD OF ENGLISH OAK (*Quercus robur* L.) AND NORTHERN RED OAK (*Quercus rubra* L.)

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SYNOPSIS. The aim of the study was to determine a relationship between the growth ring structure and the moisture content in the green wood of two species of oak trees. The species studied were English oak (*Quercus robur*) and northern red oak (*Q. rubra*), with different concentrations of tylosis.

KEY WORDS: early wood, late wood, growth ring breadth, green wood, moisture content, tylosis, *Quercus robur*, *Q. rubra*

INTRODUCTION

The study of moisture content in the green wood of early and late wood of coniferous species has shown that moisture content in the early sapwood is much higher than in late wood. The species hitherto studied in this aspect include *Pinus sylvestris* L. (Vintila 1939), *P. radiata* D. Don. (Harris 1961, Kininmonth and Whitehouse 1991), *P. insigne* from Sardinia (Giordano 1971), *Abies alba* Mill. (Michels 1943) and *Pseudotsuga menziesii* Franco (Harris 1961, Helińska-Raczkowska and Raczkowski 1979, Raczkowski et al. 2000).

This matter has not been so extensively studied in deciduous species. The available data on the subject includes fragmentary results from the Giordano (1971) study on *Quercus petraea* Liebl., *Castanea sativa* Mill. and *Populus* sp., and measurements performed during a study on collapse in *Eucalyptus regnans* F. Muell. (Innes 1996). Results also indicate higher moisture content in early than in late green wood, but such differences are generally smaller than in coniferous species.

Analysis of the above data suggests that the annual growth ring structure, and particularly the contribution of late wood, affects moisture content in green wood. Considering the scarcity of information on the subject, a study was undertaken to test the relationship between annual growth ring structure and moisture content of green wood in English oak (*Q. robur*) and northern red oak (*Q. rubra*). Species choice was determined by an abundance of tylosis in English oak vessels and its general absence in northern red oak (Hoadley 1984), which may affect moisture content, especially in early wood.

METHODS

Two experimental trees, each representing different species, were selected from the Rakownia Forest Range (Forest Experimental Station of the Agricultural University of Poznań) from among a group of trees dominant in the tree stand. English oak came from a tree stand mixed with aspen, birch trees and hornbeam. Northern red oak came from a monospecies tree stand. The English oak was felled at the beginning of February and the northern red oak at the end of March 1996. Characteristic parameters of trees are shown in Table 1.

Table 1. Characteristics of experimental trees
Tabela 1. Charakterystyka drzew doświadczalnych

Trait or parameter Cecha, parametr	Tree species – Gatunek drzew	
	(*Quercus robur*) English oak dąb szypułkowy	(*Quercus rubra*) northern red oak dąb czerwony
Tree age* [years] Wiek drzewa* [lata]	36	33
Breast diameter in bark [cm] Pierśnica w korze [cm]	17	23
Tree height [m] Wysokość drzewa [m]	20	20.5
Crown length [m] Długość korony [m]	11.3	6.7
Height to first living branch [m] Wysokość do pierwszej żywej gałęzi [m]	8.7	13.8
Crown index** Wskaźnik korony**	0.56	0.67

*Number of growth rings on stump.
**Ratio of crown length to tree height.
*Liczba przyrostów na pniaku.
**Stosunek długości korony do wysokości drzewa.

To establish a tree age, disks measuring about 25 mm in thickness were cut at a height of 1.5 m and at neck level. Immediately after being cut out, disks were tightly wrapped in aluminium and polyethylene foil to prevent loss of moisture. After transportation to the laboratory, disks were stored in a refrigerator. Characteristic disk parameters are given in Table 2.

Table 2. Cross-sectional characteristics of oak disks cut out at a level of 1.5 m from tree collar
Tabela 2. Charakterystyka przekroju poprzecznego krążków doświadczalnych pobranych z wysokości 1,5 m od szyi korzeniowej

Parameter Parametr	Tree species – Gatunek drzew	
	(*Quercus robur*) English oak dąb szypułkowy	(*Quercus rubra*) northern red oak dąb czerwony
Diameter [cm] Średnica [cm]	15	20.5
Number of annual rings Liczba przyrostów rocznych	32	31
Sapwood width [cm] Szerokość bielu [cm]	3.4	3
Number of rings in sapwood Liczba przyrostów w bielu	12	6
Sapwood width in parts of radii Szerokość bielu w częściach promienia	0.45	0.28

Slats for direct measurement, of about 20 mm widths, were cut from disks in the north-south and east-west directions. Main parameters of annual growth rings (ring width, late wood width, late wood contribution) were measured to an accuracy of 0.01 mm for disk no. 1. Slats cut from other disks were used for getting samples for moisture content measurements. From these slats, samples covering two annual growth rings were cleft in the direction from the core to the circumference. The cleavage was made under a fume cupboard in the presence of jars with water; immediately following cleavage, samples were placed in previously weighed balance vessels covered with tightly polished lids. Moisture content was measured by the gravimetric method, drying samples to a constant mass at 105°C. With the greatest possible care, a similar procedure was followed to cleave separate samples of late and early wood from selected growth rings.

RESULTS AND DISCUSSION

Growth ring analysis has shown greater dynamics of growth in northern red oak than in English oak trees (Fig. 1). The width of growth rings in these two species was comparable only over the first 10 rings around the core. The width of the outer growth rings was almost twice as much in northern red oak than in English

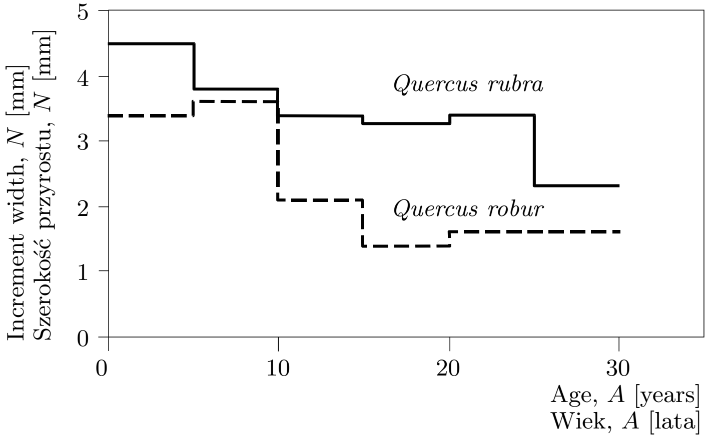

Fig. 1. The effect of cambial age on the width of annual rings in the experimental trees of English oak (*Quercus robur*) and northern red oak (*Quercus rubra*)
Rys. 1. Wpływ wieku kambialnego na szerokość przyrostów w doświadczalnych pniach dębu szypułkowego (*Quercus robur*) i czerwonego (*Quercus rubra*)

oak trees. Growth ring width is directly proportional to the width of late wood in the rings. For English oak wood, the regression equation, describing the width of the late wood contribution on the growth ring takes the form $y = 0.496\,x - 0.262$, whereas for northern red oak it is $y = 0.973\,x - 0.491$, with correlation coefficients equal to and 0.994 and 0.988, respectively.

Radial variation in the moisture content of the green wood and the variation contribution of late wood in experimental trees are shown in Figure 2. Each point in the diagram was obtained as an average for four samples. As follows from the data in Figure 2, the moisture content of the wood of the two species studied increases with the increasing age of growth rings. The mean moisture content in the English oak hardwood and sapwood was 59% and 69%, respectively, while it was 63% and 69% in the northern red oak hardwood and sapwood, respectively. Thus, the difference in the moisture content between sapwood and hardwood in English oak reaches 10%, while in the northern red oak, only 6%.

As follows from literature data (Table 3), the differences in the moisture content between the hardwood and sapwood of green oak wood are usually small and do not exceed 10%. The mean moisture content in green wood of different oak species varies from 58 to 74%. The mean moisture content in the wood of the trees studied was 63% in English oak and 66% in northern red oak.

The increase in the moisture content from the core to the circumference in oak tree wood is accompanied by a decrease in the late wood contribution in the same direction (Fig. 2), so the moisture content of green oak wood is inversely proportional to the late wood contribution. These relationships are shown in Figure 3. The correlation between the moisture content in oak tree wood and the contribution of late wood is linear and negative at a high correlation coefficient. At the

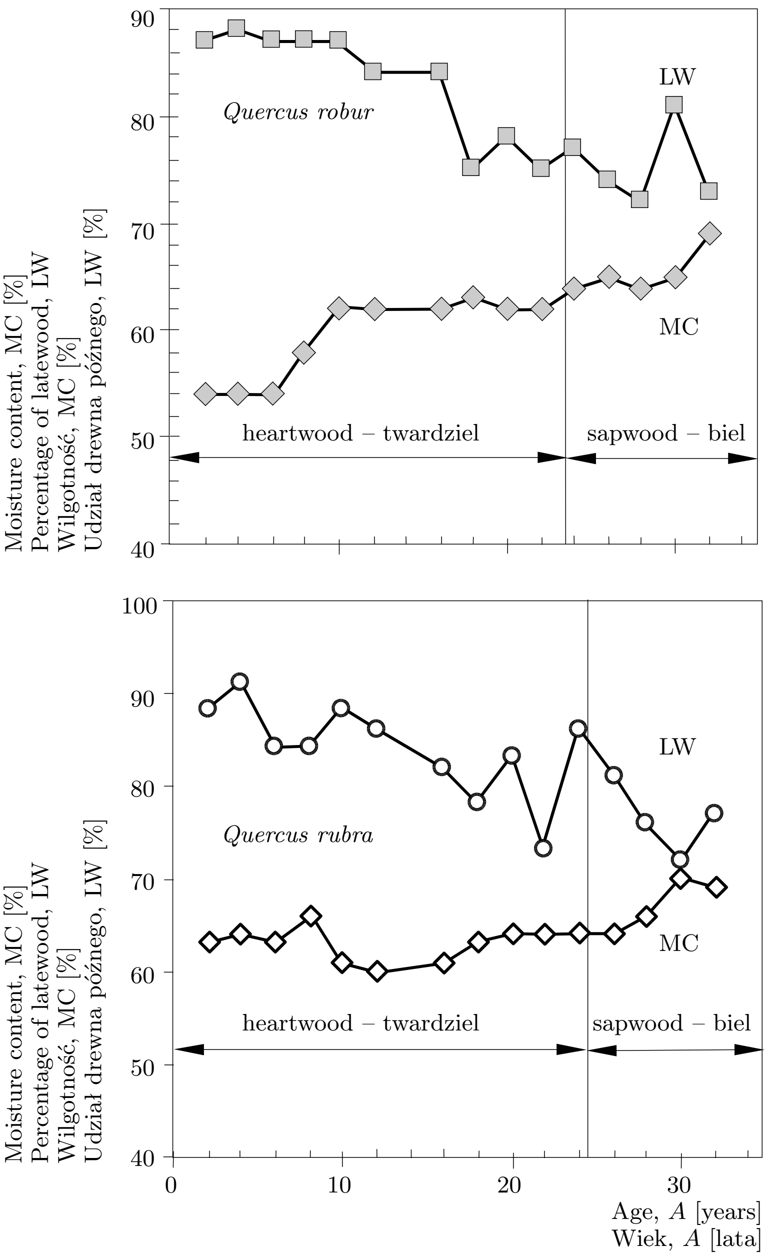

Fig. 2. The radial variation in the moisture content of green wood (MC) and the contribution of late wood (LW) over the cross-sections of the English oak (*Quercus robur*) and northern red oak (*Quercus rubra*) trunks
Rys. 2. Promieniowa zmienność wilgotności drewna w stanie świeżym (MC) i udziału drewna późnego (LW) w pniach dębu szypułkowego (*Quercus robur*) i czerwonego (*Quercus rubra*)

Table 3. Green wood moisture content in various species of the genus *Quercus*
Tabela 3. Zestawienie porównawcze wilgotności drewna w stanie świeżo ściętym różnych gatunków rodzaju *Quercus*

Species Gatunek	Tree age Wiek drzewa	Green wood moisture content Wilgotność drewna w stanie świeżo ściętym			According to Według danych
		heartwood twardziel	sapwood biel	average średnio	
	years – lata	%			
Q. robur L.	36	59	69	63	authors – autorów
Q. petraea Liebl.	75	55	60	58	Nikolov and Enčev 1967
Q. petraea Liebl.	105	59	65	61	Nikolov and Enčev 1967
Q. rubra L.	33	63	69	66	authors – autorów
Q. rubra L.	54	59	66	63	Nikolov and Enčev 1967
Q. rubra L.	–	–	–	70	Koch 1985
Q. frainetto Ten.	80	57	71	64	Nikolov and Enčev 1967
Q. cerris L.	71	56	61	59	Nikolov and Enčev 1967
Q. velutina Lam.	–	–	–	69	Koch* 1985
Q. marilandica Muench.	–	–	–	74	Koch* 1985
Q. falcata Michx.	–	–	–	67	Koch* 1985
Q. laurifolia Michx.	–	–	–	74	Koch* 1985
Q. stellata Wangenh.	–	–	–	66	Koch* 1985
Q. coccinea Muench.	–	–	–	69	Koch* 1985
Q. Shumardii Buchl.	–	–	–	69	Koch* 1985
Q. nigra L.	–	–	–	74	Koch* 1985
Q. alba L.	–	–	–	62	Koch* 1985

*Diameter of studied trees was ca 15 cm.
*Średnica badanych drzew wynosiła ok. 15 cm.

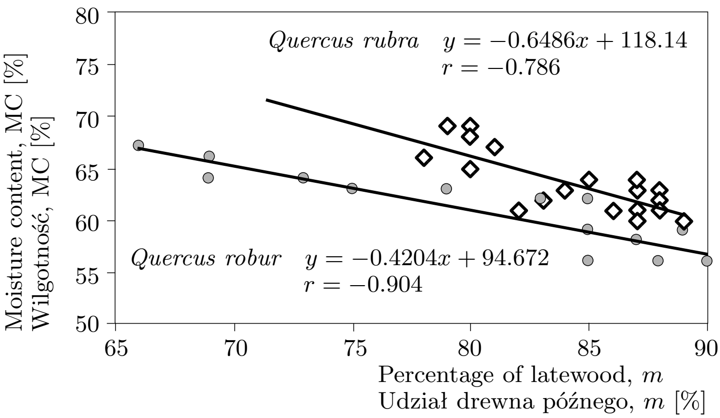

Fig. 3. The effect of the late wood contribution (m) on the moisture content in green wood of the English oak (*Quercus robur*) and northern red oak (*Quercus rubra*)
Rys. 3. Wpływ udziału drewna późnego (m) na wilgotność w stanie świeżym drewna pni dębu szypułkowego (*Quercus robur*) i czerwonego (*Quercus rubra*)

same contribution of late wood, the moisture content in the northern red oak wood is slightly higher than in the English oak wood; and the difference is the greater, the lower the contribution of late wood. A possible reason for this difference can be the presence of tylosis in the vessels of the English oak tree (the Lepidobalanus section). The vessels of the northern red oak tree (the Erythrobalanus section) are usually open and free from tylosis.

The moisture content in the early and late parts of the growth rings was estimated by extrapolating the regression equations to the contribution of late wood $m = 0$ and $m = 100\%$. The moisture content obtained in this way for early wood in English oak was 94% and in northern red oak it was 118%, whereas the moisture content in late wood was the same for both species and equalled 53%.

The moisture content measured in early and late wood of selected growth rings in the English oak and the northern red oak studied are shown in Figure 4. The moisture content of early wood tends to increase in the direction from core to circumference, whereas the moisture content in late wood is practically independent of the growth ring age. Mean moisture content in early wood of the English oak and the northern red oak is 103% and 97%, respectively, while the mean moisture content of late wood in the two species is 60% and 59%, respectively. Mean moisture content of early wood is greater than in late wood by 43% in English oak and by 37% in northern red oak.

As has been mentioned above, there is a scarcity of experimental data on moisture content variation along the growth rings of deciduous species. The only available experimental results on oak wood come from the study by Giordano (1971), who established that the mean moisture content in early wood of *Q. petraea* Liebl. in a green wood state was 83%, while that of late wood was 74%. The average difference is just 9% and avaries over individual growth rings in a range

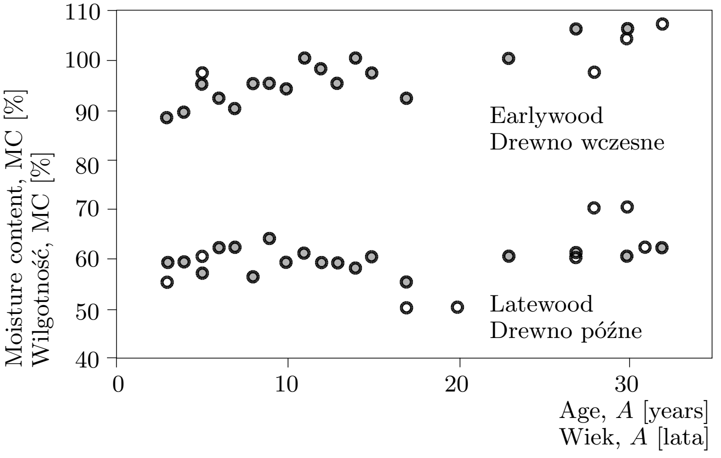

Fig. 4. Differences in moisture content in early and late green wood in selected annual rings in the English oak (*Quercus robur* – ○) and northern red oak (*Quercus rubra* – ◉)
Rys. 4. Zróżnicowanie wilgotności w stanie świeżym drewna wczesnego i późnego w wybranych przyrostach rocznych pni dębu szypułkowego (*Quercus robur* – ○) i czerwonego (*Quercus rubra* – ◉)

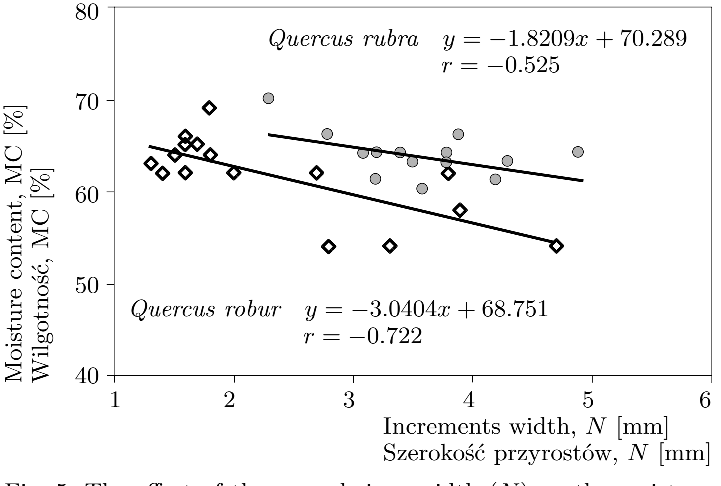

Fig. 5. The effect of the annual rings width (N) on the moisture content in green wood (MC) of the English oak (*Quercus robur*) and northern red oak (*Quercus rubra*)
Rys. 5. Wpływ szerokości przyrostów rocznych (N) na wilgotność w stanie świeżym (MC) drewna dębu szypułkowego (*Quercus robur*) i czerwonego (*Quercus rubra*)

from 0 to 25%. The same author also studied the moisture content in chestnut wood (*Castanea sativa* Mill.), to which ring-porous species belong. In chestnut wood, the mean moisture content in early and late wood was 131% and 110%, respectively. The mean difference was 21% and varied over individual rings from 4 to 45%.

The differences in the moisture content in early and late green wood are, to a significant degree, explained by differences in densities of these parts of growth rings. The same volume units of early and late wood in the fully dry state have a more varied mass; consequently, the same mass of water in early and late wood means that the moisture content in early wood is greater than that in late wood. For example, if the mass of 1 cm^3 of early and late wood in oak wood is 0.4 g and 0.8 g, respectively, the same mass of water of 0.4 g will give the moisture content of early wood of 100%, while that of late wood of 50%. These values are close to the experimental ones.

A linear negative correlation between the width of annual rings and the moisture content of green oak wood, Figure 5, suggests a possibility of estimation of the moisture content value on the basis of the easily measurable parameter – the width of annual rings. In general the fine-textured oak wood should have a greater moisture content in the green state than the wide-ringed one.

CONCLUSIONS

1. The mean moisture content over the cross section of the trunk of a green wood is 63% for English oak and 66% for northern red oak.
2. The moisture content in a green wood is slightly greater in sapwood than in hardwood and for English oak equals 69 and 59%, while for northern red oak 69 and 63%.
3. In the direction from the core to the circumference in both species, there is a tendency of the moisture content to increase with the decreasing contribution of late wood.
4. There is a negative linear correlation between the contribution of late wood and the moisture content of oak wood in the green state; correlation coefficients are – 0.904 for English oak and – 0.786 for northern red oak.
5. At the same contribution of late wood, the moisture content of northern oak wood is greater than that of English oak.
6. The moisture content measured in the green state is similar for both species and equals 100% for early wood and 60% for late wood.
7. The moisture content of early wood in the green state is about 40% higher than in late wood, irrespective of the species.
8. Differences in moisture content between early and late wood in green oak wood are mainly a consequence of differences in the densities of these two parts of annual rings.

REFERENCES

Giordano G. (1971): Technologia del legno. Vol. 1. La materia prima. Unione Tipografico – Editrice Torinese, Torino: 699-700.

Harris J.M. (1961): Water conduction in the stems of certain conifers. Nature 189 (4765): 678-679.

Helińska-Raczkowska L., Raczkowski J. (1979): Wpływ gęstości wczesnego i późnego drewna jedlicy (*Pseudotsuga menziesii* Franco) na jego właściwości oznaczone w próbie rozciągania wzdłuż włókien. Pr. Kom. Technol. Drewn. PTPN 8: 29-38.

Hoadley R.B. (1984): Understanding wood. The Tauton Press, Newton, Connecticut: 17.

Innes T.C. (1996): Collapse and internal checking in the latewood of *Eucalyptus regnans* F. Muell. Wood Sci. Technol. 30 (6): 373-383.

Kininmonth J.A., Whitehouse L.J. (1991): Properties and uses of New Zealand radiata pine. Vol. 1. Wood properties. New Zealand Forest Research Institute, Jan Bryce Printers Ltd., Rotorna: 74-76.

Koch P. (1985): Utilization of hardwoods growing on Southern Pine sites. Agric. Handbook 605. Vol. 1. U.S. Department of Agriculture, Forest Service Washington D.C.: 553-567.

Michels P. (1943): Der Nasskern der Weisstanne. Holz Roh- Werkst. 6 (3): 87-99.

Nikolov S., Encev E. (1967): Vlažnost na drevesinata v surovo sostojanije. Zemizdat, Sofia: 80-85.

Raczkowski J., Olek W., Guzenda R. (2000): Moisture evaporation rates from sapwood and heartwood samples of Douglas fir (*Pseudotsuga menziesii* Franco) green wood. Holz Roh- Werkst. 58: 247-252.

Vintila E. (1939): Untersuchungen über Raumgewicht und Schwindmass von Früh- und Spätholz bei Nadelhölzern. Holz Roh- Werkst. 2 (10): 345-357.

WPŁYW STRUKTURY PRZYROSTÓW ROCZNYCH NA WILGOTNOŚĆ DREWNA DĘBU SZYPUŁKOWEGO (*Quercus robur* L.) I CZERWONEGO (*Quercus rubra* L.) W STANIE ŚWIEŻO ŚCIĘTYM

Streszczenie

Celem pracy było bliższe rozpoznanie zależności między strukturą przyrostów rocznych i wilgotnością drewna dębu w stanie świeżo ściętym. Doświadczenia przeprowadzono na drewnie dębu szypułkowego (*Quercus robur* L.) i czerwonego (*Q. rubra* L.) o zróżnicowanej obecności wcistek.

Przeciętna wilgotność w stanie świeżym na przekroju poprzecznym badanych pni dębu szypułkowego i czerwonego jest zbliżona i wynosi odpowiednio 63% i 66%. Między udziałem drewna późnego i wilgotnością w stanie świeżym występuje korelacja negatywna. Przy tym samym udziale drewna późnego wilgotność świeżego drewna dębu czerwonego jest większa aniżeli dębu szypułkowego. Wilgotność drewna wczesnego dębu w stanie świeżym jest w wybranych przyrostach, niezależnie od gatunku, o ok. 40 punktów procentowych większa od wilgotności drewna późnego. Różnice w wilgotności drewna

wczesnego i późnego w stanie świeżym wynikają głównie z różnej gęstości drewna obu części przyrostu rocznego.

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