FOLIA
HORTICULTURAE
Ann. 17/2, 2005, 89-101

Comparison of the optical properties of the fruit tree stems: the sweet cherry, cherry, pear, common plum and walnut trees

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Key words: reflectance, absorbance, transmittance

ABSTRACT

The studies conducted in the 400 – 700 nm range of wavelength showed that, in the studied fruit trees, the reflectance of irradiation from stems was similar and equaled 9 – 15% of the falling irradiation. Together with the age of stems the absorbance increased, but the transmittance of irradiation through the cork to the chlorophyll layer of the bark decreased. Spectral research showed that with increasing wavelength, there was a decrease in absorbance but an increase in irradiation transmittance through the cork. In the PAR range, the transmittance of current-year stems in pear trees equaled 26%, in the cherry and walnut 20%, and in the sweet cherry and common plum 14%. In 3-year-old stems in pear trees, transmittance equaled about 15%, in the cherry 10%, common plum and walnut, and in the sweet cherry 6 %. In the 400 – 500 nm range, transmittance through the

cork equaled 5% in pear trees, 2% in the walnut and 1% in the cherry, common plum and sweet cherry. In older stems, irradiation transmittance decreased and in 3-year-old stems in pear trees equaled 1.6 %, and in the other species was below 1%. In the 600 – 700 nm range in current-year stems, transmittance equaled 51% in the pear, about 40% in the cherry and walnut, 30% in the common plum, and in 3-year-old stems equaled about 15% in pear trees, decreased to 10% in the cherry, common plum and walnut, and was in the sweet cherry the lowest and equaled only 6%.

INTRODUCTION

The presence of active photosynthetic chloroplasts in the bark of stems in trees and bushes is universal, especially in young stems. One factor influencing the photosynthetic pigment content as well as the photosynthetic activity of stems is the access to solar energy in the stems' chlorophyll cells. It directly depends on the bark's optical properties. In species, in which the growth in the thickness of the cork as the stem ages is insignificant, the photosynthetic pigments and the photosynthetic activity of the stems last for tens of years e.g. in *Fagus silvatica*, *Populus tremuloides* (Larcher et al. 1988, Kharouk et al. 1995), but in species, in which together with stem aging a considerable growth in the cork thickness takes place, the photosynthetic pigment content decreases and the photosynthetic function of the stems declines (Pilarski 1999).

The only known research over the photosynthetic pigment content in the bark and the optical properties of stems in fruit trees was conducted on the apple tree (Tokarz and Pilarski 2005). It showed that, in comparison with leaves, the bark of stems contained half the amount of photosynthetic pigments, but their content remained at the same level for a few years. This research also showed that, during this time, irradiation transmittance through the stem cork decreased to a small degree and this could explain the similar photosynthetic pigment content in this period. The stems exhibit photosynthetic activity throughout the year and during the leafless season are a source of assimilative substances from current production (Pilarski 1990, 2002). In the leafy season, the participation of stems in photosynthesis in CO_2 fixation is significant, as, when calculated per dm^2, it equals about 10 – 15% of the photosynthetic intensity of leaves (Pilarski 1989), and the ratio of light utilization in photosynthesis in stems is greater than when compared to leaves (Tokarz and Pilarski 2005).

The optical properties of stems, mainly cork absorbance and transmittance, which affect the amount and spectral structure of the light reaching the chlorophyll layer of the bark, greatly influence the photosynthetic activity of the bark. These optical properties depend, to a large extent, on the plant species and its environment. There is currently a lack of studies over the light conditions in the bark of other fruit trees, and in fruit-farming cultivation, planting density, pruning and shaping of trees ensure considerably better access for irradiation to the chlorophyll layer of the bark in comparison with e.g. forest groups. Therefore the photosynthetic activity of stems in fruit trees may have a greater significance on the carbon balance in plants, in comparison with forest trees. The aim of this work was to compare the optical properties of some fruit trees, which are economically important in moderate climates.

MATERIAL AND METHODS

The experiments were conducted on current-year, 1-, 2- and 3-year-old stems of the following fruit trees: the sweet cherry (*Prunus avium* L.‘Hedelfinger’), cherry (*Prunus cerasus* ‘Łutówka’), pear (*Pirus communis* ‘Konferencja’), common plum (*Prunus domestica* L. ‘Węgierka Zwykła’) and walnut (*Juglans regia* L.). Materials were collected from five trees growing in the Garlica Murowana Pomology Experimental Station near Kraków.

The optical properties of stems were measured in laboratories in the range of photosynthtically active radiation (PAR, 400 – 700 nm) using an LI-1800 spectroradiometer with an externally-integrated 12 S sphere (LI-COR USA). The reflectance of irradiation was measured from the stems, whereas transmittance was measured on isolated cork. The reflectance of stems (R) and the transmittance of cork (T) were designated using direct measurements, but the absorbance (A) of cork was calculated using the formula $A = 100 – (R + T)$. The measurements were made five times for each species and each stem age, and the results presented are arithmetic means with standard deviation.

RESULTS

The thickness of the cork in the investigated fruit trees is presented in Table1. The annual growth in the cork thickness from stems was low, therefore in the table the results of current-year and 3-year-old stems are presented. The thickness of the cork during this time increased by about 10-20% in the walnut and 50 % in the sweet cherry, doubled during the pear and common plum, however, in the cherry tree it increased 2 – 3 times.

Table 1. The thickness of cork stems of fruit trees (mm)

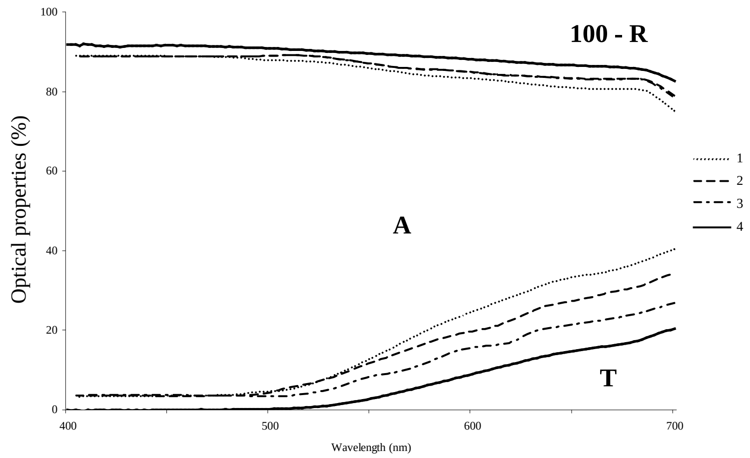
Stem age	sweet cherry	cherry	pear	common plum	walnut
Current year	0.9 – 1.0	0.5	0.4 – 0.5	0.6	0.8
3-year old	1.3 – 1.7	1.0 – 1.5	0.8 – 0.9	1.1 – 1.3	0.9 – 1.0

The results from the measurements of optical properties are illustrated in the following figures: sweet cherry - Fig.1, cherry - Fig. 2, pear – Fig. 3, common plum - Fig. 4, and walnut – Fig. 5.

Irradiation reflectance, in the PAR range, was similar in the examined species of fruit trees and in current-year stems equaled 12 – 15%, with the exception of the walnut, in which reflectance was lower and equaled 9%. The age of the stem was marked by a small reduction in reflectance, with the exception of the walnut, in which reflectance did not change with the age of stems. Spectral examinations showed that an increase in wavelength was accompanied by an increase in reflectance. In the cherry, pear and walnut, in the 650 – 680 nm range reflectance decreased, but above 680 nm increased a slightly stronger in all the investigated species.

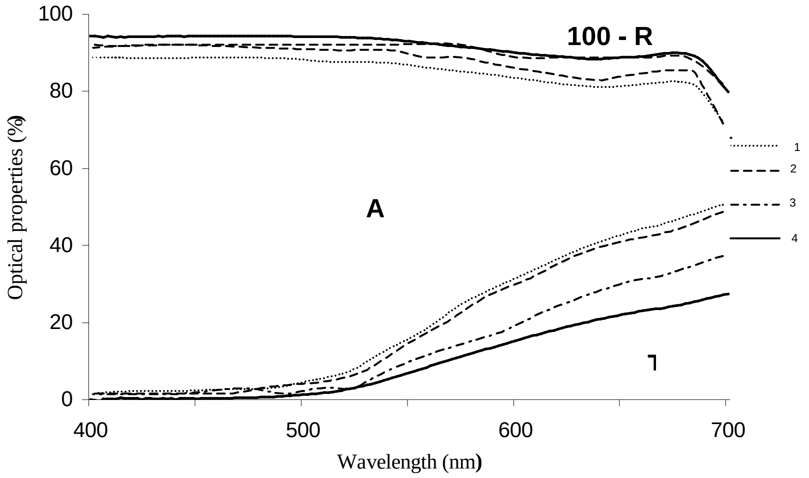
Irradiation absorbance through the cork decreased with increasing wavelength and increased with the age of stems. In the PAR range in the pear, absorbance in current-year cork was the lowest and equaled 62%, in the cherry equaled 66%, and in the remaining species: the sweet cherry, common plum and walnut ranged from 70 to 72%. In 3-year-old stems absorbance in the pear equaled 76%, in the common plum 78%, and in the sweet cherry, cherry and walnut rose to 81 – 82%. Spectral examination showed that absorbance in the cork was very high at 400 nm and equaled about 90%, both in current-year and 3-year-old stems in all the examinated species. At 700 nm, absorbance in the cork in the pear tree was the lowest and equaled 23% in current-year stems, but in 3-year-old stems increased to 37%; in the cherry it was greater and equaled 28 and 52%, respectively. In the sweet cherry, common plum and walnut in current-year stems, absorbance equaled about 35%, and in 3-year-old stems in the common plum and walnut increased to 56%, and in the sweet cherry to 62%.

Irradiation transmittance through the cork increased with wavelength, but decreased with the age of the stems. In the PAR range, transmittance in current-year stems of the pear was the greatest and equaled 26%, in the cherry and walnut equaled 20%, and in the sweet cherry and common plum was the lowest and equaled only 14%. In 3-year-old stems in the pear, transmittance equaled about 15%, in the cherry, common plum and walnut decreased to 10%, and in the sweet cherry was the lowest and equaled only 6%.



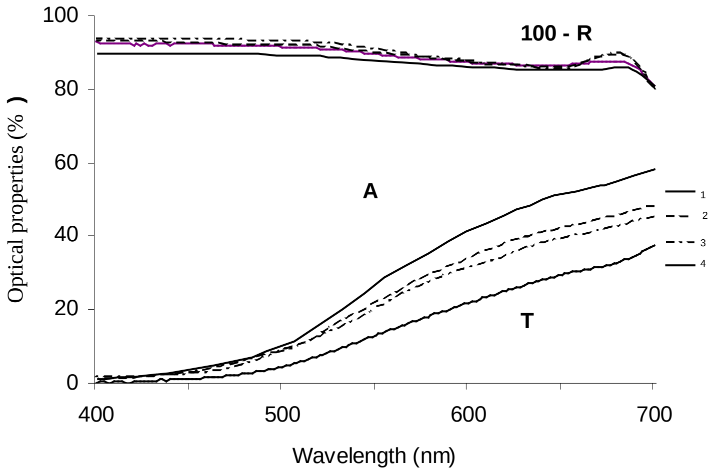
Optical properties (%)	Wavelength (nm)			
	400-700	400-500	500-600	600-700
	Current-year stems			
Reflectance	15.1 ± 0.9*	12.2 ± 0.8	14.7 ± 1.3	19.5 ± 2.1
Absorbance	70.0 ± 1.26	87.0 ± 0.8	73.0 ± 1.3	48.4 ± 2.7
Transmittance	14.9 ± 0.9	0.8 ± 0.4	12.3 ± 1.1	32.1 ± 1.7
	1-year-old stems			
Reflectance	14.8 ± 3.1	11.1 ± 1.9	14.4 ± 2.4	16.5 ± 3.4
Absorbance	73.5 ± 4.7	88.1 ± 2.3	76.2 ± 4.6	58.7 ± 8.1
Transmittance	11.6 ± 3.1	0.8 ± 0.4	9.4 ± 2.8	24.8 ± 4.3
	2-year-old stems			
Reflectance	12.7 ± 3.1	9.8 ± 1.4	12.4 ± 1.4	14.5 ± 1.9
Absorbance	78.1 ± 4.6	89.7 ± 1.9	80.4 ± 4.4	65.3 ± 6.7
Transmittance	9.2 ± 2.1	0.5 ± 0.1	7.2 ± 1.3	20.2 ± 3.6
	3-year-old stems			
Reflectance	11.7 ± 0.6	9.2 ± 1.3	11.2 ± 1.4	14.8 ± 1.6
Absorbance	82.5 ± 1.55	90.8 ± 1.4	85.5 ± 1.2	70.8 ± 2.3
Transmittance	5.8 ± 0.6	0.03 ± 0.01	3.3 ± 0.7	14.4 ± 1.0

Figure1. Spectral optical properties of the stems of the sweet cherry tree. R – reflectance, A – absorbance, T – transmittance. 1 – current-year stems, 2 – 1-year-old stems, 3 – 2-year-old stems, 4 – 3-year-old stems. n = 5. *SD



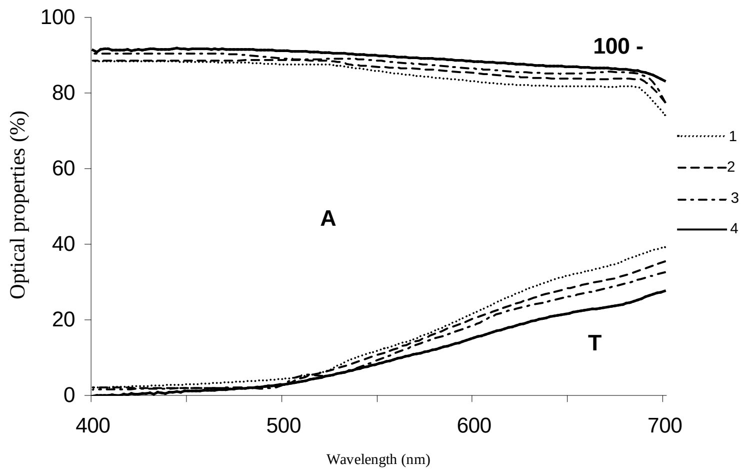
Optical properties (%)	Wavelength (nm)			
	400-700	400-500	500-600	600-700
		Current-year stems		
Reflectance	14.2 ± 0.7*	11.4 ± 0.8	13.3 ± 1.0	18.1 ± 1.3
Absorbance	66.3 ± 1.2	87.8 ± 1.6	72.3 ± 1.4	41.7 ± 3.4
Transmittance	19.5 ± 0.7	0.8 ± 0.0	16.9 ± 1.1	40.3 ± 2.5
		1-year-old stems		
Reflectance	11.8 ± 0.6	8.5 ± 0.3	10.6 ± 0.2	16.4 ± 0.8
Absorbance	69.9 ± 2.8	89.8 ± 2.8	74.0 ± 3.3	45.0 ± 3.8
Transmittance	18.3 ± 0.8	1.7 ± 0.0	15.4 ± 1.1	38.6 ± 1.6
		2-year-old stems		
Reflectance	9.6 ± 0.3	7.8 ± 0.5	8.9 ± 0.6	12.5 ± 1.1
Absorbance	78.3 ± 2.1	91.7 ± 2.4	82.8 ± 2.8	59.5 ± 3.1
Transmittance	12.1 ± 0.3	0.5 ± 0.0	8.3 ± 0.7	28.0 ± 1.9
		3-year-old stems		
Reflectance	8.4 ± 0.4	5.6 ± 0.4	7.5 ± 0.6	12.1 ± 1.0
Absorbance	82.1 ± 2.3	93.9 ± 2.4	85.1 ± 2.4	67.0 ± 1.5
Transmittance	9.5 ± 0.4	0.5 ± 0.0	7.4 ± 0.6	20.9 ± 1.3

Figure 2. Spectral optical properties of the stems of cherry tree. R – reflectance, A – absorbance, T – transmittance. 1 – current-year stems, 2 – 1-year-old stems, 3 – 2-year-old stems, 4 – 3-year-old stems. n = 5, * - SD



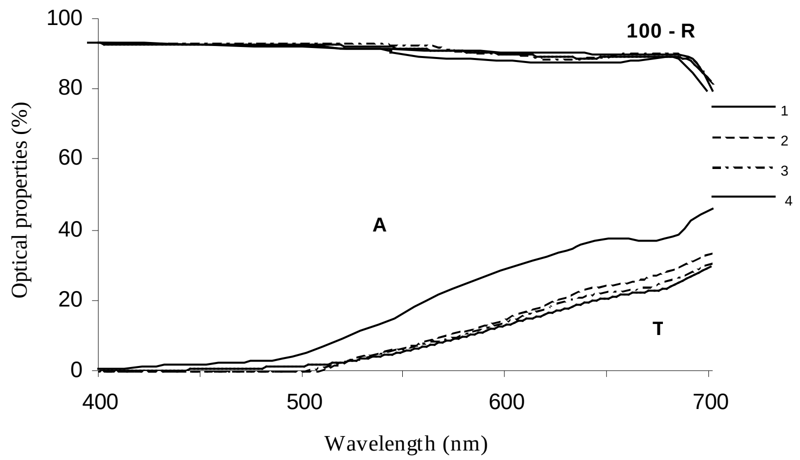
Optical properties (%)	Wavelength (nm)			
	400-700	400-500	400-500	600-700
Current-year stems				
Reflectance	12.4 ± 1.1*	10.2 ± 0.8	12.3 ± 1.1	14.9 ± 0.5
Absorbance	61.2 ± 4.1	84.7 ± 1.1	62.1 ± 2.3	34.3 ± 3.6
Transmittance	26.4 ± 3.1	5.1 ± 0.6	25.6 ± 1.6	50.8 ± 3.5
1-year-old stems				
Reflectance	9.9 ± 1.5	6.4 ± 0.9	9.4 ± 0.4	14.0 ± 1.1
Absorbance	68.5 ± 1.7	89.1 ± 1.5	72.6 ± 3.5	47.5 ± 4.7
Transmittance	21.6 ± 2.8	4.5 ± 0.7	18.0 ± 3.4	38.5 ± 4.6
2-year-old stems				
Reflectance	9.0 ± 0.4	5.8 ± 0.5	11.1 ± 1.0	14.1 ± 0.9
Absorbance	71.2 ± 1.4	90.1 ± 1.4	72.6 ± 1.1	50.8 ±1.8
Transmittance	19.8 ± 0.4	4.1 ± 0.3	16.3 ± 0.2	35.1 ± 0.6
3-year-old stems				
Reflectance	9.5 ± 0.4	6.0 ± 0.6	8.8 ± 0.9	13.7 ± 1.3
Absorbance	75.8 ±1.4	92.4 ± 1.4	78.0 ± 1.8	56.8 ± 1.8
Transmittance	14.7 ± 0.4	1.6 ± 0.2	13.2 ± 0.5	29.5 ± 0.9

Figure 3. Spectral optical properties of the stems of the pear tree. R – reflectance, A – absorbance, T – transmittance. 1 – current-year stems, 2 – 1-year-old stems, 3 – 2-year-old stems, 4 – 3-year-old stems. n = 5, * - SD



Optical properties (%)	Wavelength (nm)			
	400-700	400-500	500-600	600-700
Current-year stems				
Reflectance	14.5 ± 0.9*	11.2 ± 1.0	14.2 ± 1.2	18.2 ± 1.6
Absorbance	71.8 ± 3.0	89.8 ± 1.4	75.5 ± 1.0	51.4 ± 2.5
Transmittance	13.7 ± 1.2	1.2 ± 0.1	10.3 ± 0.7	30.4 ± 3.1
1-year-old stems				
Reflectance	13.5 ± 1.5	11.1 ± 0.3	13.1 ± 1.1	16.5 ± 1.4
Absorbance	74.3 ± 3.6	87.6 ± 2.3	77.8 ± 4.0	55.3 ± 3.8
Transmittance	12.2 ± 0.9	1.0 ± 0.1	10.0 ± 1.5	28.2 ± 1.9
2-year-old stems				
Reflectance	11.7 ± 0.8	10.2 ± 1.1	14.1 ± 1.2	14.6 ± 1.2
Absorbance	75.9 ± 5.5	88.7 ± 1.9	76.9 ± 1.6	59.4 ± 1.9
Transmittance	12.4 ± 0.9	1.1 ± 0.1	9.5 ± 0.7	26.0 ± 1.3
3-year-old stems				
Reflectance	11.3 ± 1.1	8.8 ± 0.9	10.8 ± 0.9	14.2 ± 1.0
Absorbance	78.0 ± 2.7	90.3 ± 1.5	80.1 ± 2.5	63.6 ± 3.5
Transmittance	10.7 ± 1.1	0.9 ± 0.1	9.1 ± 0.8	22.2 ± 1.8

Figure 4. Spectral optical properties of the stems of the common plum tree. R – reflectance. A – absorbance. T – transmittance. 1 – current-year stems. 2 – 1-year-old stems. 3 – 2-year-old stems. 4 – 3-year-old stems. n = 5, * - SD



Optical properties (%)	Wavelength (nm)			
	400-700	400-500	500-600	600-700
Current-year stems				
Reflectance	9.1 ± 0.6*	7.7 ± 0.6	8.9 ± 0.5	11.9 ± 0.8
Absorbance	71.4 ± 1.1	95.5 ± 1.1	73.2 ± 1.1	49.0 ± 1.5
Transmittance	19.5 ± 0.6	1.8 ± 0.5	17.9 ± 0.6	39.1 ± 0.8
1-year-old stems				
Reflectance	9.4 ± 1.5	7.8 ± 1.2	9.1 ± 1.3	11.2 ± 1.4
Absorbance	79.8 ± 4.2	91.7 ± 2.4	81.9 ± 5.4	62.7 ± 4.8
Transmittance	10.8 ± 1.5	0.5 ± 0.1	9.0 ± 1.1	26.1 ± 2.4
2-year-old stems				
Reflectance	8.5 ± 1.1	7.2 ± 1.0	8.2 ± 0.9	10.1 ± 1.2
Absorbance	79.7 ± 4.2	92.2 ± 0.4	84.6 ± 2.5	66.0 ± 4.5
Transmittance	11.8 ± 0.9	0.6 ± 0.1	7.2 ± 0.1	23.9 ± 2.2
3-year-old stems				
Reflectance	9.2 ± 1.0	7.6 ± 0.8	8.7 ± 1.2	11.5 ± 1.0
Absorbance	81.2 ± 1.6	91.9 ± 1.1	84.7 ± 1.7	66.7 ± 2.0
Transmittance	9.6 ± 1.0	0.5 ± 0.1	6.6 ± 1.2	21.8 ± 2.7

Figure 5. Spectral optical properties of the walnut tree. R – reflectance. A – absorbance. T – transmittance. 1 – current-year stems. 2 – 1-year-old stems. 3 – 2-year-old stems. 4 – 3-year-old stems. n = 5, * - SD

In the 400 – 500 nm range, irradiation transmittance of cork in current-year stems in the cherry, common plum and sweet cherry equaled only about 1%, in the walnut it was greater - 2%, and in the pear it was the highest and equaled 5%. In older stems, transmittance of this irradiation decreased and in 3-year-old stems in the pear equaled 1.6%, and in the remaining species was below 1%, being in the sweet cherry vestigial (0.03%). In the 600 – 700 nm range, transmittance was the highest in current-year stems and equaled 51% in the pear, about 40% in the cherry and walnut and 30% in the common plum. With the age of the stems, the reduction in transmittance in cork was not the same in the examined species. In the sweet cherry and common plum, transmittance lowered gradually in each year. In the walnut there was a large fall in transmittance in the cork of 1-year-old stems, but in the following years the changes were small. In the cherry, transmittance in the cork of 1-year-old stems was marginally lower than in current-year stems but large decreases in transmittance were observed in 2- and 3-year-old stems.

The present results allowed to state that, in the fruit trees investigated, irradiation reflectance from stems was similar and equaled 9 – 15% of the falling irradiation in the PAR range. Together with stem age, irradiation absorbance increased, but irradiation transmittance to the chlorophyll layer of bark decreased.

The examined tree species differed in absorbance and transmittance in the cork. Absorbance in the cork of current-year stems ranged from 61 to 72%, and in 3-year-old stems from 75 to 82%. Between 14 and 26% of irradiation reached the chlorophyll layer of the bark in current-year stems and 6 to15% in 3-year-old stems. Light which reached the chlorophyll layer of the bark contained very little irradiation in the 400 – 500 nm range, considerably more in the 500 – 600 nm range, and the most in the 600 – 700 nm range.

DISCUSSION

Solar irradiation which reaches plants undergoes physical processes: reflectance, absorbance and transmittance. Each of these processes is an important indicator of the actual physiological state of plants and the adaptation of plants to defined environmental conditions. The optical properties of leaves, stems and fruits change with age similarly to physiological features and depend on their location on the plant.

The optical properties of leaves have been researched on numerous occasions and there is much information on this subject in literature. In the PAR range, irradiation reflectance from leaves equals 6 – 20%, absorbance 50 – 95% and transmittance 1 – 15% (Pilarski 2004). In leaves, only 1- 5% of absorbed irradiation is chemically connected with the process of photosynthesis (Salle 1977).

In stems, only irradiation transmitted through the cork, whose intensity is considerably weakened and spectral structure is greatly altered in comparison with the irradiation falling on plants, can be used in the photosynthesis process. The optical properties of stems depend, to a large extent, on the plant species and the stem age.

In literature, there is little information on the subject of the optical properties of bark stems. Studies conducted in the PAR range on stems of the lilac (Pilarski 1989) and apple tree (Tokarz and Pilarski 2005) showed that, in the lilac in current-year stems, reflectance equaled 25%, absorbance 59% and transmittance 17%, and with age, the stems' optical properties changed and in 3-year-old stems reflectance decreased to 12%, absorbance grew to 79% and transmittance decreased to 10%. During this time, the cork thickness increased threefold, but the photosynthetic pigment content decreased by about 40%. In the apple tree in current-year stems, reflectance equaled 14%, absorbance 55% and transmittance 30%, and in 3-year-old stems reflectance decreased to 10%, absorbance increased to 66%, but transmittance decreased to 23%. In the apple tree, the cork thickness during this period increased by about 80%, but the photosynthetic pigment content was virtually unchanged. These results show that, in the apple tree, light conditions for photosynthesis are considerably more favorable in comparison with the lilac (Pilarski 1989).

In the species examined in this study, irradiation transmittance, in the PAR range, through current-year cork, only in the pear tree was slightly less than in the apple tree and a little more than in the lilac. In the walnut and cherry it was about 1/3 less, and in the common plum and the sweet cherry it was less than half that in the apple. In 3-year-old stems in all investigated species, transmittance in the cork was less than 50% that in 3-year-old stems in the apple, but in comparison with 3-year-old lilac stems, in the pear it was about 50% greater, in the walnut, common plum and cherry it was similar and only in the sweet cherry was it about 50% less.
Studies in the lilac (Pilarski 1989) showed that the photosynthetic activity of chloroplasts isolated from 3-year-old stems equaled about 50% of the activity of chloroplasts isolated from leaves, and about 60% in comparison with those isolated from current-year stems. The results for irradiation transmittance through the cork of the examined fruit trees, like those gained for the lilac, allowed the assumption that their photosynthetic activity might be similar to the photosynthetic activity of stems in the lilac. This assumption was also supported by the large amount of irradiation in the 600 – 700 nm range transmitted through the cork, whose utilization coefficient in the photosynthesis process was greater when compared with irradiation in the 400 – 500 nm range.

The present results showed that the optical properties in the fruit tree stems of investigated species assured efficiency in the functioning of photosynthetic apparatus.

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PORÓWNANIE WŁAŚCIWOŚCI OPTYCZNYCH DRZEW OWOCOWYCH: CZEREŚNI, WIŚNI, GRUSZY, ŚLIWY I ORZECHA WŁOSKIEGO.

Streszczenie: Badania przeprowadzone w zakresie 400 – 700 nm długości fali świetlnej wykazały, że u badanych drzew owocowych refleksja promieniowania od pędów była podobna i wynosiła 9 – 15% padającego promieniowania. Z wiekiem pędów wzrastała absorpcja a malała transmisja promieniowania przez korek do warstwy chlorofilowej kory. Spektralne badania wykazały, że wraz ze wzrostem długości fali malała absorpcja i wzrastała transmisja promieniowania przez korek. W zakresie PAR transmisja pędów bieżącego rocznika u gruszy wynosiła 26%, u wiśni i orzecha 20%, a u czereśni i śliwy 14%. W pędach 3-letnich u gruszy transmisja wynosiła około 15%, u wiśni, śliwy i orzecha 10%, a u czereśni 6%. W zakresie 400 – 500 nm transmisja korka wynosiła u gruszy 5%, orzecha 2%, a u wiśni, śliwy i czereśni 1%. W starszych rocznikach pędów transmisja promieniowania malała i w pędach 3-letnich u gruszy wynosiła 1,6%, a u pozostałych gatunków poniżej 1%. W zakresie 600 – 700 nm w pędach bieżącego rocznika transmisja wynosiła u gruszy 51%, wiśni i orzecha około 40%, śliwy 30%, a w pędach 3-letnich u gruszy wynosiła około 15%, w przypadku wiśni, śliwy i orzecha malała do 10%, a u czereśni była najmniejsza i wynosiła tylko 6%.

Received March 24, 2005; accepted September 30, 2005