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ORIGINAL PAPER

Parameters of strip roads in selected thinned pine stands of younger age classes

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ABSTRACT

Strip roads are designed and created according to guidelines contained in industry standards that state basic parameters such as the width and distance between them. The aim of the research was to analyze these parameters after thinning and to compare these parameters to industry guidelines. The research was carried out in 2021 in six 33-34 year old Scots pine *Pinus sylvestris* stands in which the strip roads were cut in the years 2007-2020 in two variants: parallel and perpendicular to the tree rows. The measurements were in accordance with Sondells method and covered a total of 34 strip roads (16 parallel and 18 perpendicular). The statistical verification of the results consisted in assessing the significance of the differences in the values of the analyzed parameters between individual roads (within one plot), between plots, and between variants. Statistically significant differences regarding the widths of individual strip roads were found in three plots (two with roads parallel and one perpendicular to tree rows). In regard to distance, statistically significant differences were found in four plots, (two with parallel and two with perpendicular roads). Statistically significant differences were also found between plots in regard to width in all cases for parallel and perpendicular roads and for distance in all cases for parallel roads and in two cases for perpendicular roads. Comparison of the analyzed parameters between variants showed that parallel roads had significantly greater widths (avg. 424.4 cm vs 392.1 cm) and distance (30.7 m vs 23.7 m) than perpendicular roads. Assessment of the compliance of the analyzed parameters with industry guidelines showed that the width of strip roads was in most stands compliant with the currently applicable 'Principles of Forest Utilization', while the distances between roads were usually greater than recommended.

KEY WORDS

cut-to-length method, early thinning of the 2nd and 3rd age classes, mechanized harvesting, *Pinus sylvestris*, the layout of skid roads, timber extraction

Introduction

Strip roads, as defined in the 'Principles of Forest Utilization' (ZUL, 2019), are thin strips of forest area with trees removed intended for logging and skidding of wood and performing other forest management activities. The principles in ZUL (2019) emphasize that strip roads are vital

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for the use of modern technologies and for improving work organization as well as occupational health and safety. Modern technologies in forest utilization are based on harvesters felling and processing trees and forwarders extracting timber to the forest road (skidding). In Poland, in the past several years there has been a significant increase in the number of these machines (Jodłowski and Moskalik, 2016; Mederski *et al.*, 2016; Bodył, 2022; Więsik, 2022). Harvesters and in particular forwarders require wide strip roads to move around the work site due to their large dimensions. The issue of stand accessibility is particularly important in the case of thinnings where optimization of the network layout of strip roads becomes a priority for high productivity (Søvde *et al.*, 2019). Laser scanning technologies utilizing forest digital maps might be useful in this regard (Sterenczak and Moskalik, 2014). Restricting machine travel to strip roads results in lower damage to trees and soil which is the main purpose of strip roads (Bort *et al.*, 1993; Han and Kellogg, 2000; Suwała, 2004; Horn *et al.*, 2007; Picchio *et al.*,2012; Schäffer *et al.*, 2012; Stempski and Jabłoński, 2018; Picchio *et al.*, 2020; Kulak *et al.*, 2023; Naghdi *et al.*, 2023).

Advancements in the mechanization of timber harvesting have always been accompanied by a discussion related to the issue of making forest stands available through a network strip roads. In Poland, this began in the mid-1990s when the State Forests purchased 15 Timberjack 1010 forwarders and proceeded to implement the cut-to-length method in logging. This method has been used in Scandinavia for a long time (Nurminen *et al.*, 2006; Nordfjell *et al.*, 2010; Malinen *et al.*, 2016), and recently it is gaining popularity in the Baltic countries (Moskalik *et al.*, 2017). The introduction of the cut-to-length method in Poland was initially based on the manual 'Guidelines for the design and construction of strip roads' (Rzadkowski, 1995). These guidelines contained recommendations for the design and layout of skidding roads mainly for semi-mechanical technologies in which tree felling and processing operations were performed with chainsaws. In the following years, especially after Poland joined the European Union, a dynamic increase in the mechanization of timber harvesting began which meant that the provisions based on these 'Guidelines' were losing their relevance with each passing year (Jodłowski, 2010). As an effect of these changes, the new guide called 'Guidelines for providing access to forest stands with a network of strip roads' (Zarządzenie, 2016) was established. According to these new rules, the strip roads for specialized forestry logging machines could be as much as 5 m wide (in the previous guidelines they were generally up to 4 m), and the distance between them was set to 20 m (or a multiple of this distance). At the end of 2019, these were eventually replaced by the current guide 'Principles of Forest Utilization' (ZUL, 2019) which returned to the maximum strip road width of 4 m (possibly greater if the road was created by cutting down two rows of trees). However, the distance of the strip roads in the cut-to-length methods remained at 20 meters.

The aim of this study was to assess the real parameters of strip roads (width and distance between them) in thinned pine stands and to check the compliance to industry guidelines as related to these measurements. The scope of the research covered roads established in two variants – parallel and perpendicular to the rows of trees. The hypothesis was that parallel strip roads are wider and the distances between them are shorter in comparison to the perpendicular ones.

Materials and methods

Field measurements of strip road parameters were made in Oborniki Forest District in the eastern part of Notecka Forest in central Poland on six sample plots as described in Table 1.

Strip roads were planned in 2007-2008 and 2016-2020 by the same regional forester and marked using a marking ribbon. The parameters of the strip roads were measured using the established Sondells method (Sondell, 1974) (Fig. 1). The widths of the strip roads were determined at each ten-meter section along their length (after marking the boundaries of these sections on the ground) with an accuracy of 5 cm. The width consisted of the distance from the middle of the wheel rut after the machine had passed through and to the side of the nearest tree on both sides of the same wheel rut – A and B on Fig. 1 (Sondell, 1974; Bobik, 2008; Modig *et al*., 2012). The width of each ten-meter section was the sum of these measurements, and the width of the entire strip road was the average of all the sections (11-20 sections were measured per strip road). The distance between the roads was measured in the direction perpendicular to the road axis at the border points of the 10-meter sections using a TruPulse 360B laser rangefinder with an accuracy of 10 cm.

The statistical verification of the results involved assessing the significance of the differences in the values of the analyzed parameters within individual plots (between individual strip roads), between sample plots and in variants regarding the orientation of roads relative to the tree rows. If the variables of three or more groups met the condition of being normally distributed, a one-way ANOVA was used, otherwise the Kruskal-Wallis test was performed. In the case of variables with two groups, the Mann-Whitney U test was used (due to the lack of normality in the distribution). The compliance of results' distribution with the normal distribution was tested with the Shapiro-Wilk test. All the analyses were conducted in the Statistica version 13.3 software package (TIBCO Software Inc., 2017) at the significance level α=0.05.

Table 1.
General characteristics of sample plots

Sample plot	SP1par	SP2par	SP3par	SP4per	SP5per	SP6per
Variant		parallel			perpendicular	
Age [years]	43	34	43	36	34	33
DBH [cm]	16	11	15	14	12	14
Height [m]	16	13	17	15	13	15
Year of cutting strip roads	2008	2007	2016	2019	2017	2020

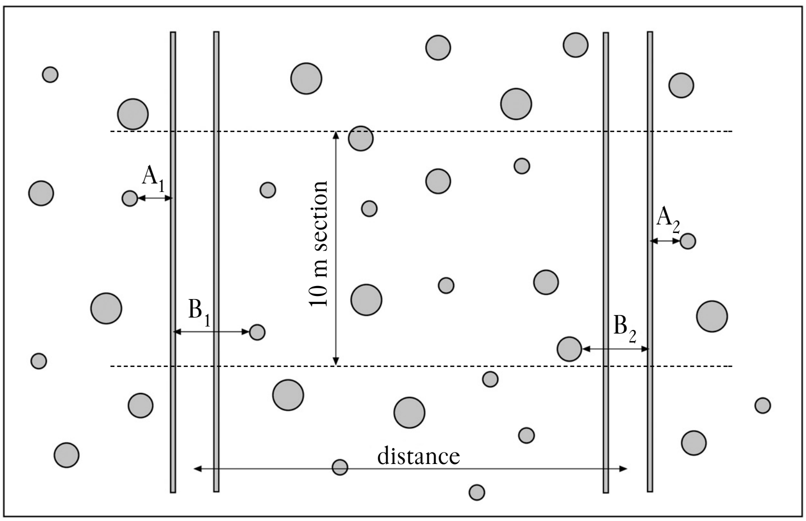

Fig. 1.
Measurements of strip road width (A+B) and the distance between them on each 10-m section (based on Sondells method)

Results

The parallel strip roads on plot SP1par had an average width of slightly over 360 cm to almost 510 cm, while in SP2par the results were definitely more consistent ranging from about 440 cm to 460 cm (Table 2). In plot SP3par the widths were smaller than in the other two with the average ranging from almost 350 cm to 380 cm. Differences between minimal and maximal values were between 380 and 405 cm. The statistical verification of the results showed significant differences in the width of the strip roads in SP1par (H=53.7, p<0.001) and SP3par (H=16.2, p<0.001), while in SP2par there were no such differences (H=2.1, p=0.910).

The average width of the strip road in subdivision SP3par was almost 360 cm while in the other two plots it exceeded 400 cm with the higher result in plot SP2par (Table 2). The statistical verification of the results showed significant differences between the plots. The strip roads in SP1par were significantly wider than in SP3par, and those in SP2par were wider than in the other two sample plots (Table 2).

Most of the perpendicular roads in plot SP4per had an average width of over 420 cm, only in one case was it below 400 cm. However, in plot SP6per only one road was wider than 400 cm, while the width of the others did not exceed this value and ranged between 380 and 400 cm. In plot SP5per the average width of all roads did not exceed 400 cm. The differences between the minimum and maximum values were definitely smaller than in the case of roads parallel to the rows of trees. These ranged from 185 cm in plot SP6per, up to 200 cm in SP4per and up to 305 in SP5per. Statistically significant differences between the widths of individual strip roads were found in plot SP4per (H=14.2, p=0.010), while in SP6per there were no differences (F=1.68, p=0.147) as was the case in SP5per (H=12.7, p=0.050).

The average width of roads for whole sample plots ranged from about 365 cm to almost 420 cm (Table 2), and the average width of more than 400 cm was found only in one plot (SP4per) in contrast to the roads parallel to the rows of trees (Table 2). Statistically significant differences between plots were found. The roads in plot SP4per were significantly wider than in the other two, and the roads in plot SP6per were also significantly wider than those in SP5per (Table 2).

The average distances between parallel strip roads in plots SP1par and SP3par typically exceeded 35 m, while in SP2par they were within a smaller range of about 21.5-23.5 m. Differences between minimum and maximum distances ranged from about 6.5 m in plots SP1par and SP2par to 9 m in SP3par. The variability of the results was definitely lower than in the case of the road widths with the coefficient of variability for plots SP1par and SP3par at the

Table 2.

The widths of strip roads in sample plots in both to variants. Different letters next to medians indicate statistical significance (p<0.001)

Sample plot	$\bar{x}$	Me	Min.	Max.	$V_{\%}$
		Parallel to the rows of trees			
SP1par	433.9	432.5a	315.0	720.0	15.7
SP2par	449.3	470.0b	295.0	675.0	12.0
SP3par	357.9	335.0c	305.0	700.0	19.1
		Perpendicular to the rows of trees			
SP4per	418.8	412.5a	345.0	545.0	10.3
SP6per	389.6	385.0b	320.0	505.0	8.8
SP5per	364.9	355.0c	280.0	585.0	12.5

$\bar{x}$ – mean, Me – median, Min. – minimum, Max. – maximum, $V_{\%}$ – coefficient of variation level of 1-3%, but higher values were found for plot SP2par (4-6%). Statistically significant differences in the distances of roads were found in plots SP1par (H=88.9, p<0.001) and SP3par (U=0.00, p<0.001), while in plot SP2par there were no differences (H=2.1, p=0.91).

The average distances between parallel strip roads calculated for whole sample plots ranged from almost 23 m up to 34.5 m and 37 m (Table 3). The Kruskal-Wallis test showed statistically significant differences between plots, with the distances in plot SP1par significantly greater than in SP3par and SP2par. The distances in plot SP2par were also significantly greater than the distances in plot SP3par (Table 3).

In contrast to the plots with parallel roads, the distances between perpendicular ones did not exceed 30 m in any case. In sample plot SP4per these ranged between 25 and 29 m, in SP5per 24-27.5 m, and in SP6per 20-21 m. The differences between the extreme distance values ranged from 11.5 m in plot SP5per, up to 7.6 m in SP4per, and 4.9 m in SP6per. Statistically significant differences were found in sample plot SP4per (F=11.84, p<0.001) and SP5per (H=25.8, p<0.001), while in sample plot SP6per there were no such differences (H=5.7, p=0.22).

The results for the whole sample plots with perpendicular roads (Table 3) showed similar average distances in sample plots SP4per and SP5per with the difference being only 0.7 m. In SP6per the distances between the roads were definitively smaller (an average slightly over 20 m). The Kruskal-Wallis test showed statistically significant differences between plots with the distances in plot SP6per being significantly smaller than in both plots SP4per and SP5per (Table 3).

The descriptive statistics pooled for all sample plots within a variant, are presented in Table 4. These results indicate that the roads running parallel to the tree rows were wider and more distant from each other than the roads perpendicular to the tree rows. Differences were statistically significant (Mann-Whitney U test) for both width and distance (Table 4).

Table 3.
Distances between strip roads in sample plots in both variants. Different letters next to medians indicate statistical significance (p<0.001)

Sample plot	$\bar{x}$	Me	Min.	Max.	$V_{\%}$
Parallel to the rows of trees					
SP1par	36.9	37.8a	32.1	41.2	7.4
SP2par	22.8	23.0b	19.0	25.6	5.5
SP3par	34.4	34.1c	31.4	38.0	6.8
Perpendicular to the rows of trees					
SP4per	26.1	26.1a	21.7	29.3	5.4
SP6per	20.4	20.2b	18.0	23.3	5.6
SP5per	25.4	25.2a	21.0	32.5	8.2

Table 4.
Comparison of the results of road widths and their distances depending on the variant

Variant	$\bar{x}$	Me	Min.	Max.	V%	p
Width [cm]						
Parallel	424.4	435.0	295.0	720.0	16.8	<0.001
Perpendicular	392.1	385.0	280.0	585.0	11.8	
Distance [m]						
Parallel	30.7	32.4	19.0	41.2	22.7	<0.001
Perpendicular	23.7	24.1	18.0	32.5	12.8	

Discussion

Through the research in this study the actual real world parameters of strip roads were measured and compared to guidelines. Widths and distances between roads were calculated using the established Sondells method (Sondell, 1974). The use of this procedure allowed the opportunity to obtain results which described the strip roads layout well. It should be noted that the width of the strip road is not an unambiguous term because the roads are not separate from the rest of the forest stand. According to the literature (Isomäki and Niemistö, 1990), the width of the road can be considered not only from the point of view of logging, but also as a factor influencing the forest growth. The research also distinguish the 'so-called outer width' which is measured by taking into account the distances to all trees bordering the road, and not only the two closest trees. For stands with a similar age to the ones measured in this study, the widths of their strip roads ranged from 375 cm to as much as 626 cm with an average of 462 cm which is wider than any of the widths obtained in this research. The width of strip roads from a logging point of view must allow the machine to move freely and is therefore largely a function of a machine's width. On the other hand, the width of the road from the perspective of timber production reduces the production area which is caused by conducting cuttings to create the roads (Eriksson, 1987; Niemistö, 1989; Mäkinen *et al.*, 2006). The wider the roads, the larger the area excluded from production. However, it is worth noting that not all of the production area is lost because the resulting free space above the roads is gradually filled in by tree crowns (called the 'increment from overexposure') (Eriksson, 1987; Mäkinen *et al.*, 2006; Horák and Novák, 2009; Wallentin and Nilsson, 2011; Kuliešis *et al.*, 2018; Stempski *et al.*, 2020).

This research measured the width of the strip roads and their distance in two variants: perpendicular and parallel to the rows of trees. A clause on the possibility of using roads parallel in relation to rows of trees was only included in the latest guidelines contained in the 'Principles of Forest Utilization' (ZUL, 2019). All previous industry regulations guidelines from 1995 (Rzadkowski, 1995) and 2016 (Zarządzenie, 2016) recommended a perpendicular orientation. Roads running parallel to rows of trees are easier to create but according to our results they are wider, and thus result in a greater reduction of the production area of the stand. Moreover, as observed by Rzadkowski (1997), the side edges of parallel roads create the densest possible arrangement of trees in a young, dense stand. Performing extraction or technological operations in such conditions may result in damage to a large number of trees. In such conditions, a perpendicular arrangement is preferable as the gaps between the rows create natural corridors enabling access with a harvester head or a forwarder grapple to the heaps of wood left for extraction. In older stands, where the rows of trees are no longer easily noticeable, this is less important.

The results showed that the width of the strip roads parallel to rows of trees in all three stands were in compliance with the current guidelines contained in the 'Principles of Forest Utilization' (ZUL, 2019). However, in two stands the widths exceeded 4 m (Table 5) which according to all previous guidelines would be too wide.

Removal of two rows of trees with a standard distance between them of about 1.5 m results in a width that exceeds 4 m. Such a large width is not necessary for the efficient movement of most harvesters and forwarders currently used in Poland. Furthermore, the roads perpendicular to rows of trees are usually narrower than 4 m which should be another reason for planning the roads this way. It is also worth noting that a 4 m width is most commonly suggested by literature for the cut-to-length method (Ovaskainen *et al.*, 2006; Ovaskainen and Riekki, 2022). The published Polish 'Principles of Forest Utilization' allow for widths greater than 4 m only in the

Table 5.
Comparison of measured strip road parameters with industry guidelines

Sample plot	Width [m]		Distance [m]	
	measured	PFU[1]	measured	PFU[1]
Parallel to the rows of trees				
SP1par	4.3		36.9	
SP2par	4.5	≤4 m (>4 m)[2]	22.8	20 m
SP3par	3.6		34.4	
Perpendicular to the rows of trees				
SP4per	4.2		26.1	
SP6per	3.9	≤4 m	20.4	20 m
SP5per	3.7		25.4	

[1]Principles of Forest Utilization
[2]in case of removing two rows of trees

case of the removal of two rows of trees. However, some studies (Dušek *et al.*, 2015) point out that even wide strip roads do not diminish the stand productivity.

The distance between strip roads as recommended in the current 'Principles of Forest Utilization' is 20 m (ZUL, 2019) which roughly corresponds to double reach of a harvester crane. In our research, this exact value was achieved in only one stand (SP6per), while in the other stands the distance was wider. The largest distance of 37 m was found in plot SP1par where the strip roads were cut in 2008. Such distances could be considered compliant with the guidelines of 1995 (Rzadkowski, 1995) only if these roads were used for wire skidding. In the case of strip roads cut in 2016, 2017 and 2019 in plots SP3par, SP5per and SP4per the distance (according to the guidelines of that time) should have been 20 m or multiples of 20 m. However, in reality it was greater, especially in SP3par. Results obtained by Ovaskainen and Reikki (2022) using field-reference measurements were much closer to the desired 20 m spacing (20.6-21.7 m). However, it is worth noting that the layout of strip roads was the responsibility of harvester operators.

Conclusions

- The results confirmed the hypothesis that parallel strip roads have a greater width compared to perpendicular ones, but the hypothesis that there is a shorter distance between strip roads in these variants is not confirmed. Parallel roads had statistically significant greater widths and distances between each other than roads located perpendicularly to rows of trees.
- The width of the strip roads parallel to rows of trees was in accordance with the currently applicable guidelines in 'Principles of Forest Utilization'. In the case of perpendicular roads, this parameter was slightly higher than the value from the guidelines in one stand, but in the other two it was compliant with the guidelines.
- Larger discrepancies from industry guidelines were found for the distances between roads. Only in one stand with roads perpendicular to rows of trees was this parameter compliant with the guidelines. In the remaining stands, the distances were greater than those recommended in 'Principles of Forest Utilization', especially in the case of roads running parallel to rows of trees.

Authors' contributions

W.S. – conceptualization, methodology, material collection, statistical analyses, investigation, writing – original draft preparations; K.P. – formal analysis, investigation, manuscript review and editing; P.Z. – formal analysis, investigation.

Conflict of interest

The authors declare no conflicts of interest.

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STRESZCZENIE

Parametry szlaków zrywkowych w trzebieżach wybranych drzewostanów sosnowych młodszych klas wieku

Pozyskiwanie drewna w Polsce odbywa się coraz częściej z wykorzystaniem harwesterów i forwarderów. Maszyny te (z reguły o znacznych gabarytach) do sprawnego i bezpiecznego dla środowiska przemieszczania się w drzewostanie wymagają tras przejazdów w postaci szlaków operacyjnych (zrywkowych, technologiczno-zrywkowych). Szlaki należy projektować i wykonywać według

zasad zawartych w branżowych wytycznych, które określają ich podstawowe parametry, tj. szerokość i odległość między nimi. Od 2020 r. w Lasach Państwowych obowiązują w tym zakresie „Zasady użytkowania lasu", które zastąpiły „Wytyczne do udostępniania drzewostanów siecią szlaków operacyjnych" z 2016 r. Zasady użytkowania lasu wprowadziły możliwość projektowania szlaków operacyjnych o dowolnym przebiegu względem rzędów drzew (prostopadłym, ukośnym, równoległym), natomiast wcześniejsze wytyczne zalecały generalnie przebieg prostopadły. Celem badań była ocena szerokości szlaków i odległości między nimi w praktyce pozyskiwania drewna w cięciach pielęgnacyjnych. Parametry te policzono dla szlaków o równoległym i prostopadłym przebiegu względem rzędów drzew. Przyjęto hipotezę badawczą zakładającą, że szlaki równoległe są szersze i umieszczone w mniejszych odstępach niż szlaki prostopadłe. W pracy dokonano także oceny zgodności analizowanych parametrów szlaków z branżowymi wytycznymi. Badania przeprowadzono w 2021 r. na 6 powierzchniach z drzewostanami sosnowymi *Pinus sylvestris* L. w wieku 33-43 lata, w których szlaki wycięto w latach 2007-2020 (tab. 1). W 3 drzewostanach szlaki przebiegały równolegle do rzędów drzew (pierwsze 3 powierzchnie z tab. 1), w 3 pozostałych prostopadle. Pomiarami objęto łącznie 34 szlaki operacyjne (18 o przebiegu prostopadłym i 16 o przebiegu równoległym do rzędów drzew). Szerokość szlaków określano na każdym 10-metrowym odcinku ich długości. Była ona sumą odległości od osi śladu po przejeździe maszyny do najbliższego drzewa z jednej i drugiej strony szlaku (ryc. 1). Odległości między szlakami mierzono prostopadle do osi szlaku w punktach granicznych 10-metrowych odcinków jego długości. Pomiary szerokości wykonano taśmą samozwijającą z dokładnością do 5 cm, a pomiary odległości między szlakami dalmierzem laserowym TruPulse 360B z dokładnością do 10 cm. Dla analizowanych parametrów każdego szlaku (w przypadku odległości – par szlaków) policzono podstawowe statystyki opisowe (średnia, mediana, minimum, maksimum, współczynnik zmienności). Statystyki te policzono także dla wszystkich szlaków na każdej powierzchni i łącznie dla wszystkich szlaków równoległych i prostopadłych do rzędów drzew. Statystyczna weryfikacja wyników polegała na ocenie istotności różnic wartości analizowanych parametrów na poszczególnych powierzchniach (między szlakami na każdej powierzchni), między powierzchniami i w zależności od usytuowania szlaków względem rzędów drzew. Wyniki badań potwierdziły hipotezę o większej szerokości szlaków równoległych niż prostopadłych, natomiast nie potwierdziły hipotezy o mniejszych odległościach między tymi szlakami. Analiza szerokości szlaków w obrębie poszczególnych powierzchni wykazała różnice między szlakami (różnice statystycznie istotne stwierdzono na dwóch powierzchniach ze szlakami równoległymi do rzędów drzew i jednej z prostopadłymi). Różnice stwierdzono także między powierzchniami (statystycznie istotne między wszystkimi powierzchniami, zarówno ze szlakami równoległymi, jak i prostopadłymi do rzędów drzew) (tab. 2). W przypadku odległości między szlakami w obrębie poszczególnych powierzchni statystycznie istotne różnice stwierdzono w dwóch drzewostanach ze szlakami równoległymi do rzędów drzew i dwóch z prostopadłymi. Analiza wyników między powierzchniami wykazała różnice istotne statystycznie między wszystkimi powierzchniami ze szlakami równoległymi i w dwóch przypadkach powierzchni ze szlakami prostopadłymi (odległości na jednej powierzchni były istotnie mniejsze niż na dwóch pozostałych – tab. 3). Porównanie analizowanych parametrów między szlakami równoległymi i prostopadłymi wykazało, że szlaki równoległe miały statystycznie istotnie większe szerokości i odległości między sobą niż szlaki prostopadłe (tab. 4). Ocena zgodności parametrów z branżowymi wytycznymi wykazała, że szerokości szlaków były w większości drzewostanów zgodne z obecnie obowiązującymi „Zasadami użytkowania lasu", natomiast odległości między szlakami były najczęściej większe od zalecanych (tab. 5).