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A PROPOSED METHODOLOGY FOR SHAPING THE FARM-FOREST BOUNDARY IN THE PROCESS OF CREATING SPATIAL ORDER IN RURAL AREAS

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Abstract. The rather inefficient production of agricultural raw materials on low-quality soils requires solutions enabling alternative uses of these soils. One of the ways to manage such soils is afforestation. However, this process cannot be performed on a random basis but it should favour sustainable development of rural areas, be in harmony with both rural inhabitants and nature and create spatial order. This paper presents an attempt to develop a method for qualifying land for forest development, and for setting a boundary between forest lands and utilised agricultural lands, depending on the intensity of potential of suitability for afforestation. While developing the method, the methodology assumptions were applied of the surface potential method developed by Borkowski [2001] and subsequently modified for the purposes of solving the presented problem.

Key words: farm-forest boundary, afforestation, potential of suitability for afforestation method

INTRODUCTION

In 2009, over 93% of Poland's area was occupied by rural areas [Obszary … 2011], including ca 61% of arable land [Rocznik statystyczny... 2010]. Utilised agricultural lands are characterised by low productivity, since most of them are class IV, V or VI soils which account for 73% of the total arable land in total [Rocznik statystyczny... 2010]. These determinants result in rural areas in Poland being the so-called „problem" areas [Bański 2002]. Therefore, it may be considered that in the areas where economic difficulties occur in adapting soil for crop production, an alternative use of production resources

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(mainly earth) should be introduced, e.g. through afforestation. This thesis allows assuming that the methodology of determining the farm-forest boundary may be applied almost all over Poland.

WORK METHODOLOGY

The proposed method is used to identify areas, i.e. distinguish units and their boundaries with the use of the potential suitability for afforestation. Depending on the total estimated intensity of occurrence of all specified parameters of the natural environment features, it enables one to indicate the suitability of an area for afforestation. Such an approach allows analysing both the parameters of natural environment features and the correlations between them.

For the purposes of the proposed method, the **"potential of suitability for afforestation"** was defined. It is a synthetic, abstract measure of the natural environment value, which reflects the estimated potential capacity of a set of selected natural environment features for afforestation on the assumed basic field. The lower the basic field's suitability for agricultural utilisation is, the greater is the value of the measure, which reflects the reasonable use of agricultural production space. On the other hand, the potential of suitability for afforestation resulting from the natural environment features was named the **"potential of the natural environment feature"**. The potential of the natural environmental feature is an analytic abstract measure of the natural environment value, which reflects the potential capacity of a given natural environment feature for afforestation as regards a specified part of the examined area, called the basic field. In turn, the term **"potential of the parameter of natural environment feature"** was attributed to the potential fraction of the natural environment feature. This is an analytic abstract measure of the natural environment value, which reflects the estimated potential capacity of an area to be afforested, taking into account the area occupied by a given parameter of the natural environment feature within the entire research area [Pawlewicz 2007].

Thanks to literature studies it was possible to determine a list of natural environment features which may contribute to forest-type land development and guarantee preservation of spatial order in rural areas. The following natural environment features were selected and marked with detailed parameters: soil quality classes: (1a) very good and good – I, II and III class; (1b) medium – IV and V class; (1c) poor – VI and VIz class, and waste land; soil agricultural suitability: (2a) complexes: wheat very good (1), wheat good (2), rye very good (4), grassland, very good and good (1z); (2b) complexes: wheat defective (3), rye good (5), rye poor (6), cereal/fodder strong (8), grassland medium (2z); (2c) complexes: rye very poor (7), cereal/fodder poor (9), arable soils intended for grassland (14), grassland poor and very poor (3z); occurrence of devastated, degraded and potentially threatened lands: (3a) lands under threat of erosion – lands under medium, strong and very strong threat of erosion were taken into account; (3b) bluffs, earth subsidence, ravines, scarps, landslides; (3c) contaminated lands; 3d) dumps and areas where sand, gravel, peat or clay was extracted; water conditions of soils: (4a) dry and periodically dry soils – complexes:

3, 5, 6 and 7; (4b) soils with a favourable water circulation system or easy control thereof (with optimum moisture content) – complexes: 1, 1z, 2 and 4; (4c) periodically moist soils – complexes 8 and 2z; (4d) periodically or permanently waterlogged soils – complexes: 9, 14 and 3z; downslope: (5a) lands with downslope below 15 %, (5b) lands with downslope of 15% – 30 %, 5c) lands with downslope above 30 %; vegetation covering: (6a) surface woodlots, (6b) tree clumps, (6c) single trees, (6d) sodding; location: (7a) lands being buffer zones around industrial plants and waste dumps; (7b) lands located at seepage spring areas of rivers or streams, on watersheds, along river banks and on the shores of lakes and other water bodies; (7c) lands located along dirt roads or poorly paved roads; (7d) lands located along well-paved roads or bitumen roads; (7e) lands with no access road; (7f) lands located in forest enclaves and semi-enclaves.

In order to verify and select the weights of natural environment features and parameters, which determine the potential of suitability for afforestation, a survey was conducted using a modified Delphi method (belonging to the group of heuristic methods in forecasting), hereinafter referred to as the **expert method**.

While making selection, the respondents[1] were guided by the following scale:

- **afforestation recommended (required)** – score = 3 – the parameter of the natural environment feature indicates a typically forest-type method of development. The most appropriate method of development is the forest function;
- **afforestation possible** – score = 2 – the parameter of the natural environment feature indicates the forest-type or agricultural method of development. Afforestation is possible as well as agricultural development;
- **afforestation not recommended** – score = 1 – the parameter of the natural environment feature indicates that the agricultural function would be a "better", more reasonable method of development.

The analysis was conducted in the following stages:

1. Calculating the area indicator of the *j*-th parameter of the *a*-th natural environment feature in the research area (wp_{aj})

Area indicator defines the area share, expressed as a percentage, of each parameter of a given natural environment feature in the total area of all parameters of that feature over the whole examined area.

$$wp_{aj} = \frac{p_{aj}}{\sum p_{aj}} \cdot 100\% \qquad (j = 1, 2, ..., m) \qquad (a = 1, 2, ..., n) \qquad (1)$$

where:

wp_{aj} – area indicator of the *j*-th parameter of the *a*-th natural environment feature;
p_{aj} – the surface area of the *j*-th parameter of the *a*-th natural environment feature (expressed in ares);
Σp_{aj} – a sum of areas of individual parameters of the natural environment feature (expressed in ares).

[1] Respondents were researchers employed at the University, doctoral candidates as well as forest inspectorate employees.

2. Calculating the suitability indicator of the j-th parameter of the a-th natural environment feature for afforestation (wpz_{aj})

Suitability indicator, expressed as a percentage, defines the fractional power of impact of each parameter of a given natural environment feature on afforestation in the total power of impact of a given feature on afforestation, over the whole research area, depending on the area it occupies.

This indicator was developed separately for each parameter, taking advantage of the experts' knowledge, in order to obtain information on the power of impact of the j-th parameter of a-th natural environment feature on afforestation. The obtained raw data were converted to an abstract measure using an arithmetic mean.

$$wpz_{aj} = \frac{\overline{X} \cdot p_{aj}}{\sum(\overline{X} \cdot p_{aj})} \cdot 100\% \qquad (j = 1, 2, ..., m) \qquad (a = 1, 2, ..., n) \qquad (2)$$

where:

wpz_{aj} – suitability indicator of the j-th parameter of the a-th natural environment feature for afforestation;

p_{aj} – surface area of the j-th parameter of the a-th natural environment feature (expressed in ares);

$\overline{X}_{aj}$ – an arithmetic mean of the j-th parameter of the a-th natural environment feature, obtained from research conducted using the expert method and calculated using the following formula:

$$\overline{X_{aj}} = \frac{\sum X_{aj}}{n_{x_j}} \qquad (j = 1, 2, ..., m) \qquad (a = 1, 2, ..., n) \qquad (3)$$

where:

ΣX_{aj} – the sum of indicated values of the j-th parameter of the a-th natural environment feature;

n_{xaj} – a total number of indicated values of the j-th parameter of the a-th natural environment feature.

3. Calculating the potential of the parameter of the natural environment feature (V_{aj})

$$V_{aj} = \frac{wpz_{aj}}{wp_{aj}} \qquad (j = 1, 2, ..., m) \qquad (a = 1, 2, ..., n) \qquad (4)$$

where:

V_{aj} – the potential of the j-th parameter of the a-th natural environment feature;

wpz_{aj} – suitability indicator of the j-th parameter of the a-th natural environment feature for afforestation;

wp_{aj} – an area indicator of the j-th parameter of the a-th natural environment feature.

The value of the measure of the parameter of the natural environment feature is directly proportional to the intensity of the parameter indicating the possibility of afforestation.

In further analysis, the research area was divided with a regular square grid into basic fields with an area of 10 ares each. Cadastral, soil-agricultural and topographic maps were used together with aerial photographs and field inspections were carried out.

Such an approach makes it possible to calculate the potential of the natural environment feature in each basic field of the examined area. Hence, the formula for the **potential of the natural environment feature** assumes the following form:

$$VP_{a_i} = \frac{\sum (V_{aj} \cdot p_{aj_i})}{\sum p_{aj_i}} \qquad (i = 1, 2, ..., z); \quad (j = 1, 2, ..., m); \quad (a = 1, 2, ..., n) \qquad (5)$$

where:
VP_{aj} – a value of the potential of the *a*-th natural environment feature in the *i*-th basic field;
V_{aj} – the potential of the *j*-th parameter of the *a*-th natural environment feature;
p_{aji} – area of the *j*-th parameter of the *a*-th natural environment feature in the *i*-th basic field (expressed in ares);
Σp_{aji} – a sum of areas in the *i*-th basic field of the individual parameters of the *a*-th natural environment feature (expressed in ares).

Upon performing interpolation, the obtained values of the potentials of natural environment features were divided into three groups to determine the possibility for conducting afforestation:
– group 1 – afforestation required < 2b; max.);
– group 2 – afforestation possible < b; 2b);
– group 3 – afforestation not recommended (min; b).

where:
min. – the lowest value out of the set of values of the obtained potentials of natural environment features;
max. – the highest value out of the set of values of the obtained potentials of natural environment features;

b – the class length calculated using the following formula [Sobczyk 2004]: $b \cong \frac{R}{k}$,
where *R* – the range, i.e. the difference between the highest and the lowest value of a feature in the set: $R = x_{\max} - x_{\min}$.

k – class, i.e. a tolerance within which the examined features are grouped.

4. Determining the potential of suitability for afforestation and setting out the farm-forest boundary

Calculation of the values characterising the potential results of successive fields of reference provided the basis for calculating the synthetic values of the potential of suitability for afforestation.

The value of the potential of suitability for afforestation may be therefore presented using the following formula:

$$VZ_{ni} = \sum VP_{ai} \qquad (i = 1, 2, ..., z) \qquad (a = 1, 2, ..., n) \tag{6}$$

where:

VZ_{ni} – the potential of suitability for afforestation of the i-th basic field for n examined natural environment features;

ΣVP_{ai} – a sum of values of potentials of n examined natural environment features in the i-th basic field.

The potential of suitability for afforestation defines the possibilities for afforestation in a given basic field depending on the total evaluation of all examined natural environment features.

It was assumed that for the purposes of standardising the potential results of individual natural environment features while determining the potential of suitability for afforestation, and thereby the farm-forest boundary, the ranking of the obtained results should be performed. The following principle was complied with during the ranking: the highest value, equal to 3, was received by potentials belonging to group 1 – afforestation required; value equal to 2 was received by potentials belonging to group 2 – afforestation possible; the lowest value, equal to 1, was received by potentials belonging to group 3 – afforestation not recommended.

Bearing in mind the effective use of space and the creation of spatial order, it should be stated that not all lands characterised by high potential of suitability for afforestation (group 1) should be intended for afforestation. This results from the fact that the farm-forest boundary cannot contribute to afforestation in random places, separated from the existing forest complexes, nor can it lead to the atomisation of the forest area and including patches of forests among arable fields. Therefore, the following assumptions should also be taken into account while determining the farm--forest boundary in the process of rural space order creation [Wytyczne... 1989, 2003, Krajowy... 2003]:

- a surface area of the newly created afforested places – it was assumed that a newly created forest complex cannot be smaller than 3 ha;
- fitting the boundaries of the newly created afforested sites into field invariants – this means that while creating spatial order it should be taken into account that the boundaries of the newly created afforested places should, as far as possible, run along field invariants, such as: water bodies, water courses, road networks, built-up areas, etc.
- incorporating small arable land complexes into the newly created forest complexes – thereby integrating the farm-forest boundary into the surrounding landscape.

RESEARCH RESULTS

An example of the use of the proposed method

In order to test the proposed method, an analysis of the power of impact of individual natural environment features on afforestation was conducted, using an example of a selected land survey cadastral district – Węgajty in Jonkowo commune in the province of Warmia-Mazury. Each feature was analysed separately and then, based on the obtained results, maps of the potential of individual features were developed. The maps, developed using contour lines, were used for unambiguous identification of areas that were most suitable for afforestation. Thanks to the results of the potential of features it is possible to indicate the "final" potential, i.e. the potential of suitability of afforestation. On this basis it is possible to pinpoint a potential farm-forest boundary, being a component of the rural area space consistent with the idea of spatial order, formed – artificially or naturally – deliberately, aesthetically and in an orderly manner.

At the first stage, the potential of the individual features was determined. These values constitute components of the "final" potential (of suitability for afforestation), which provides an opportunity to make a decision on intending lands for afforestation. Therefore, the value of the potential of individual features may be interpreted as an impact on the given feature on the overall suitability of land for development as a forest. The data is compiled in table 1.

Upon determining the potential of individual parameters of features, the potential of the feature was calculated in each basic field using formula (5), and subsequently the obtained potential values were divided into three categories defining the possibility to conduct afforestation.

Based on the potential values of natural environment features and formula (6), the potential value of suitability for afforestation was calculated. Therefore, the possibility to evaluate the existing condition of space within the research object (Węgajty cadastral district) was obtained, which made it possible to indicate the prospects for the use of a given area in terms of afforestation.

As a result of the analysis of the potential of suitability for afforestation of Węgajty cadastral district, the location was identified as on area with favourable conditions which predispose them for afforestation. The conducted delimitation made it possible to distinguish areas that were most suitable for afforestation and prepare a map (using contour lines). Areas were plotted together with the farm-forest boundary, and areas suitable for afforestation were clearly located therein. Based on the determined farm-forest boundary, three areas were identified within the cadastral district, which were afforested or may be intended for afforestation. One of them, located in the north-west, constitutes a complementation of the largest forest complex within the cadastral district. It comprises six existing forest complexes (a total area of 96.30 ha). As a result of the conducted research, it was proposed to expand it to the area of 112.77 ha. Another area was located in the east of the cadastral district, along the railway line. It connects three existing small forest complexes, with a total area of 2.02 ha. The new area will occupy 24.26 ha. The last of the new areas was located in the west of the cadastral district, also along the railway line. Its area is 13.66 ha. The farm-forest boundary determined within

Table 1. Potential parameters of natural environmental features
Tabela 1. Potencjały parametrów cech środowiska przyrodniczego

Feature parameter designation Oznaczenie parametru cechy	Feature Cecha Feature parameter Parametr cechy	p_{aj} [are] [ar]	wp_{aj}	$\bar{x}_{aj}$	wpz_{aj}	V_{aj}
1	2	3	4	5	6	7
	Soil quality classes – Bonitacja gleb					
1a	very good and good (I, II, III class) bardzo dobra i dobra (klasy: I, II, III)	100.95	0.23	1.02	0.11	0.48
1b	medium (IV, V class) średnia (klasy: IV, V)	34799.80	81.27	1.93	74.24	0.91
1c	poor (VI, VIz class), N słaba (klasy: VI, VIz), N	7918.55	18.49	2.93	25.65	1.39
	Soil agricultural suitability Przydatność rolnicza gleb					
2a	complexes: wheat very good (1), wheat good (2), rye very good (4), grassland, very good and good (1z) kompleksy: pszenny bardzo dobry (1), pszenny dobry (2), żytni bardzo dobry (4), użytki zielone bardzo dobre i dobre (1z)	2697.92	6.51	1.00	3.36	0.52
2b	Complexes: wheat defective (3), rye good (5), rye poor (6), cereal--fodder strong (8), grassland medium (2z) kompleksy: pszenny wadliwy (3), żytni dobry (5), żytni słaby (6), zbożowo-pastewny mocny (8), użytki zielone średnie (2z)	32743.91	79.04	1.86	76.05	0.96

cd. tabeli 1
cont. Table 1

1	2	3	4	5	6	7
2c	complexes: rye very poor (7), cereal-fodder poor (9), arable soils intended for grassland (14), grassland poor and very poor (3z) kompleksy: żytni bardzo słaby (7), zbożowo-pastewny słaby (9), gleby orne przeznaczone pod użytki zielone (14), użytki zielone słabe i bardzo słabe (3z)	5983.13	14.44	2.76	20.59	1.43
	Occurrence of devastated, degraded and potentially threatened lands Występowanie gruntów zdewastowanych, zdegradowanych oraz potencjalnie zagrożonych					
3a	lands under threat of erosion grunty zagrożone erozją	2004.71	84.24	2.85	84.67	1.00
3b	bluffs, earth subsidence, ravines, scarps, landslides urwiska, zapadliska, wąwozy, skarpy, osuwiska	322.44	13.55	2.75	13.13	0.97
3c	contaminated lands grunty skażone	52.48	2.21	2.83	2.20	1.00
3d	dumps and areas where sand, gravel, peat or clay was extracted hałdy i tereny po wyeksploatowanym piasku, żwirze, torfie, glinie	–	–	2.85	–	there are no nie występują
	Water conditions of soils Warunki wodne gleb					
4a	dry and periodically dry soils – complexes: 3, 5, 6, 7 gleby suche i okresowo suche – kompleksy: 3, 5, 6, 7	25529.66	61.63	2.59	68.93	1.12
4b	soils with a favourable water circulation system or easy control there of (with optimum moisture content) – complexes: 1, 1z, 2, 4 gleby o korzystnym układzie stosunków wodnych lub łatwej ich regulacji (optymalnie uwilgotnione) – kompleksy: 1, 1z, 2, 4	2697.92	6.51	1.29	3.62	0.56

cd. tabeli 1
cont. Table 1

1	2	3	4	5	6	7
4c	periodically moist soils – complexes: 8, 2z gleby okresowo wilgotne – kompleksy: 8, 2z	11418.20	27.56	1.97	23.37	0.85
4d	periodically or permanently waterlogged soils – complexes: 9, 14, 3z gleby okresowo lub trwale podmokłe – kompleksy: 9, 14, 3z	1779.18	4.29	2.20	4.08	0.95
	Downslope Spadek terenu					
5a	below 15% poniżej 15%	39200.79	91.41	1.19	84.96	0.93
5b	15–30%	3271.13	7.63	2.15	12.86	1.69
5c	of 30% powyżej 30%	411.34	0.96	2.90	2.18	2.27
	Vegetation covering Pokrycie roślinnością					
6a	surface woodlots zadrzewienia powierzchniowe	1973.09	74.98	2.78	81.29	1.08
6b	tree clumps kępy drzew	103.39	3.93	2.24	3.43	0.87
6c	single trees pojedyncze drzewa	32.18	1.22	1.76	0.84	0.68
6d	sodding zadarnienia	522.69	19.86	1.86	14.44	0.73

cd. tabeli 1
cont. Table 1

1	2	3	4	5	6	7
	Location Lokalizacja					
7a	lands being buffer zones around industrial plants and waste dumps grunty stanowiące strefy izolacyjne wokół zakładów przemysłowych, wysypisk odpadów	220.21	0.51	2.92	0.73	1.44
7b	lands located at seepage spring areas of rivers or streams, on watersheds, along river banks and on lakes' and other water bodies' shores grunty położone przy źródliskach rzek lub potoków, na wododziałach, wzdłuż brzegów rzek oraz na obrzeżach jezior i zbiorników wodnych	601.64	1.38	2.76	1.89	1.37
7c	lands located along dirt roads or poorly paved roads grunty położone wzdłuż dróg gruntowych lub utwardzonych o złej nawierzchni	3930.34	9.03	2.14	9.56	1.06
7d	lands located along well-paved roads or bitumen roads grunty położone wzdłuż dróg utwardzonych o dobrej nawierzchni lub dróg asfaltowych	35635.10	81.91	1.95	79.07	0.97
7e	lands with no access road grunty, do których brakuje drogi dojazdowej	2394.99	5.51	2.36	6.42	1.17
7f	lands located in forest enclaves and semi-enclaves grunty położone w enklawach i półenklawach leśnych	721.42	1.66	2.83	2.32	1.40

Source: Own research[2]
Źródło: Opracowanie własne

[2] Since detailed calculations related to the execution of research were quite extensive, so they were not included in the paper, but can be provided by the author upon request.

the cadastral district enabled increasing the forest area from 98.53 ha to 150.68 ha. The delineation of the potential farm-forest boundary of the analysed Węgajty cadastral district is presented in figure 1.

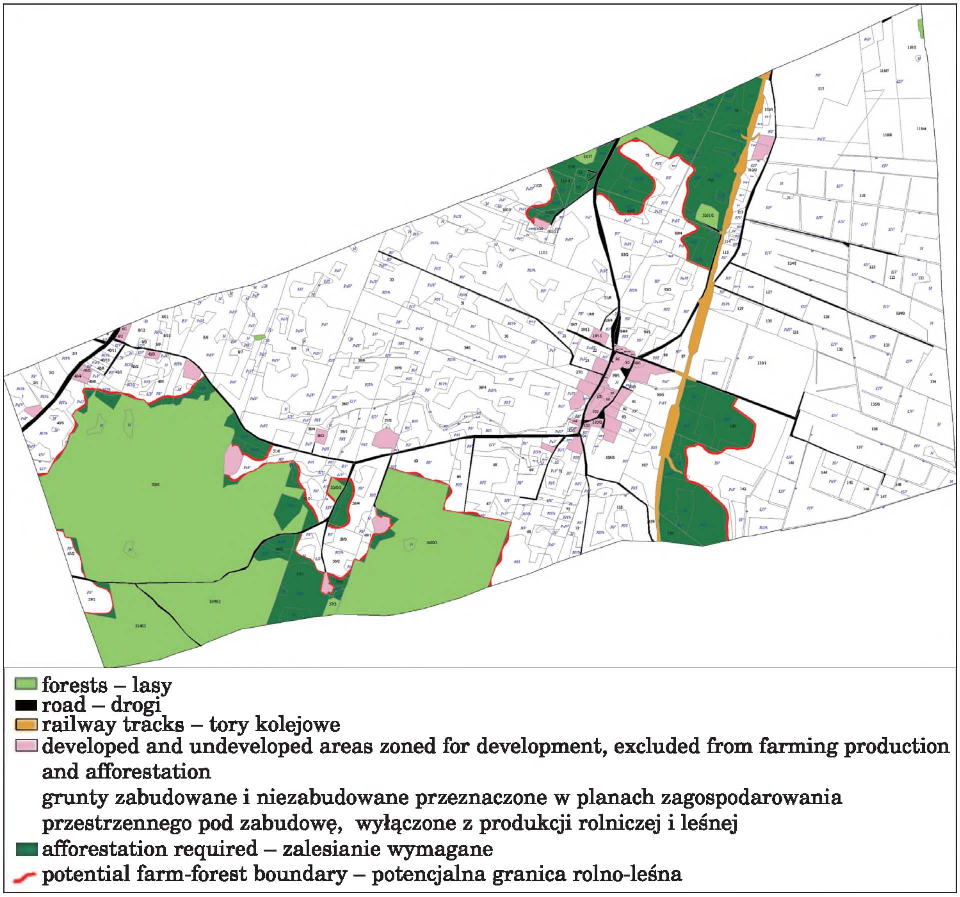

Fig. 1. Delineation of potential farm-forest boundary of the analysed Węgajty cadastral district
Rys. 1. Przebieg potencjalnej granicy rolno-leśnej analizowanego obrębu Węgajty
Source: Own research.
Źródło: Opracowanie własne.

The analysis of the research object rated the space in terms of afforestation. Areas with a high potential of suitability for afforestation were identified and they were reduced in order to best fit them into the surrounding landscape, thereby not introducing excessive patchwork within arable lands. Delimitation may be one of the components enhancing the spatial order within the research area.

CONCLUSIONS

The proposed method has proved its suitability for practical applications. It may be applied in planning studies while determining the farm-forest boundary at all spatial planning levels in the case of preparing area development plans or land use plans of a commune.

Despite the fact that the research was local in nature and shows that the thesis is correct on the selected research object, the algorithm of behaviour is universal and may be applied by various administrative bodies with minor modifications (the application or development of appropriate computer software is mainly of relevance here).

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PROPOZYCJA METODYKI KSZTAŁTOWANIA GRANICY ROLNO-LEŚNEJ W PROCESIE KREOWANIA ŁADU PRZESTRZENI WIEJSKIEJ

Streszczenie. Mało efektywna produkcja surowców rolnych na gruntach słabej jakości wymusza wprowadzanie rozwiązań, które pozwolą te grunty wykorzystać alternatywnie. Jednym ze sposobów ich zagospodarowania może być zalesianie. Jednak proces ten nie może odbywać się przypadkowo. Powinien sprzyjać zrównoważonemu rozwojowi obszarów wiejskich. Musi być akceptowany przez mieszkańców wsi, być w zgodzie z przyrodą oraz tworzyć ład przestrzenny.W artykule przedstawiono próbę opracowania metody kwalifikacji terenów do zagospodarowania leśnego oraz wyznaczania granicy między gruntami leśnymi a użytkowanymi rolniczo, w zależności od natężenia potencjału podatności na zalesianie. Wykorzystano założenia metody potencjałów powierzchniowych, opracowanej przez Borkowskiego [2001], którą zmodyfikowano na potrzeby rozwiązania przedstawionego problemu.

Słowa kluczowe: granica rolno-leśna, zalesianie, metoda potencjału podatności na zalesianie

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