Original paper

PEDOCLIMATIC CONDITIONS OF BLACK WALNUT (*Juglans nigra* L.) USED FOR AGROFORESTRY SYSTEMS IN SLOVAKIA

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Abstract

The possibilities of using black walnut (*Juglans nigra* L.) from a production-ecological point of view in agroforestry systems in Slovakia were tested on the pilot research-demonstration plot of Kosihy nad Ipľom. This tree is a woody plant that is growing to a lesser extent in forest stands but it can be found also in ornamental gardens and parks. However, its potential for agroforestry systems use in the framework of sustainable management of agricultural land has not yet been re-evaluated. It can generate very interesting and promising commodities for farmers, both in terms of fruit production and high-quality wood that is well monetized on the market. The methodology is based on the identification of agro-ecological conditions of black walnut (*Juglans nigra* L.) growing and proposal of areas suitable for these trees planting (ranked as very suitable, suitable, and unsuitable). The land evaluation units – BPEJs (© VÚPOP Bratislava) were separately evaluated based on several major land properties like climate region, soil type, soil texture, sloppiness, exposition, and skeleton content. The ArcGIS mapping software system was applied for the map of suitability of agricultural land for the cultivation of black walnut. Soil survey was supported by soil sampling and analyses of soil properties. By results only 610,000 ha from agricultural land acreage are very suitable for black walnut cultivation in Slovak Republic, and 765,000 ha are moderately suitable. This identification of areas can support the creation of methodologies modifying national legislation that allow the creation of agroforestry systems in Slovakia in accordance with the European Union legal order.

Keywords: black walnut (*Juglans nigra* L.), agroforestry, suitability of agricultural land in Slovakia

INTRODUCTION

Agroforestry can be considered as a dynamic system combining trees, and/or livestock on the same area of land in some form of spatial arrangement or temporal sequence. Agroforestry systems, which are sustainable and multifunctional, provide many environmental benefits. They contribute to the climate change adaptation and mitigation, protect the soil, enhance biodiversity, and improve the overall condition of the landscapes. They are also beneficial for the local rural economy, as those improved landscapes offer cultural and recreational opportunities. Prominent examples are the dehesa in Spain (oak trees with livestock grazing underneath) (Rigueiro-Rodroguez, McAdam, Mosquera-Losada (eds) 2009, Campos, Ovando, & Montero 2008) and the Fennoscandian area (covering Finland, Norway, and Sweden in their entireties, and a part of Russia), where reindeer husbandry is practised (EP 2020).

The agroforestry is an approach to land use that incorporates trees into farming systems and allows to produce trees and crops and/or livestock from the same piece of land. It has a rich history of development and has been practised for more than 6000 years (Gordon, Newman, Coleman 2018). Agroforestry in temperate regions is defined as "Intensive land management that optimizes the benefits (physical, biological, economic, social) from biophysical interactions created when trees and/or shrubs are deliberately combined with crops and/or livestock (Gold & Garrett 2009). The agroforestry concept was developed in tropical regions within concept of developing nations for both, food and wood resources (Huxley 1983, MacDicken & Vergara 1990, Kidd & Pimentel 1992).

Agroforestry systems present nowadays a significant innovation trend in the agricultural sector in Europe (EP 2020). There are systems, where on one site tree species are grown together with agricultural production. Effectiveness of these systems is based on reducing external inputs and offsetting them by better management in ecological links (Gordon, Newman, Coleman 2018). In agriculture of the Slovak Republic, in the transition on bio-agriculture sector and on the principles of "European Green Deal", agroforestry systems will play a crucial role in solving the current problems (Jankovič 2015a, b). It is especially in marginal areas when compared to traditional agricultural systems, where they can provide diversified, and thus higher incomes to farmers (Jankovič & Hrebík 2016, Jankovič, Hrebík & Slamečka 2017). Among other things, they can give job opportunities for residents of rural areas, and thus also help to solve the negative consequences of the persistent trend of "rural depopulation" (Jankovič, Hrebík 2016, Jankovič Hrebík, Slamečka 2017).

At the same time, they represent a significant mitigation measure on climate change. According to Newman & Gordon (2018) agroforestry has the potential to both:

1) To help to mitigate the effects of climate change by reducing the production of greenhouse gases (GHG) by, for example, switching energy production from fossil fuels to biomass production.
2) To help people to adapt to the climate change by encouraging the use of trees for better management of water to reduce climate-change linked flooding. Evidence is also emerging that increased "woodiness" in agriculture may help to sequester and store carbon, especially in soils and this is an additional mitigation effect.

These challenges include 1) population growth, 2) climate change (with catastrophic weather events, 3) food security in parts linked to the changes in diet, and 4) lack of energy, lack of water and insufficient supply of many of the inputs necessary for agricultural sustainability. The interlinkages are complex, which can be dramatically increased by human demand for land, water, and other natural resources. It should be noted that climate change brings opportunities in terms of new platform for smart agriculture in temperate agroforestry (Rigueiro-Rodroguez, McAdam, Mosquera-Losada (eds) 2009, Vacek *et al.* 2009, Shepard 2013, Pástor 2016, Shepard 2013, Stejskal 2017).

Black walnut and other fruit trees are promising fructiferous tree species, which potential is not yet fully utilized in our conditions, i.e., for agroforestry. Many references on the cultivation of black walnut can be found primarily in European and American sources (Ares & Bauer 2004, Atchinson 2005, Hrib 2005, Cremer *et al.* 2008, Nicolescu *et al.* 2020, Russel, Hemery 2004, Šindelář & Novotný 2004). Also, other tree species can be evaluated for agroforestry production like mountain ash (Bakay & Pástor 2014), chestnut (Pástor *et al.* 2017), field maple (Bakay, Kollár & Pástor 2014), and others (Bublinec 2002, Pekárová, Hanisko, Kováčiková 2013, Vilček, Bedrna 2007).

Black walnut (*Juglans nigra* L.) is a deciduous tree being native to eastern North America, where it grows predominantly near rivers and coasts from southern Ontario, west to southeast South Dakota, south to Georgia, north to Florida, and southwest to Texas. By the human activity, in the 17^{th} century, the black walnut trees spread to Europe, where, in addition to park plantings, they were also experimentally planted in forestry. In its homeland, it is found on the edges of forests and near watercourses. In our conditions, it grows up to a height of approximately 30 m. The crown of the tree is spread out and the bark is deeply furrowed. Globular fruits darken during ripening. They are nutritionally valuable and used primarily in pharmaceuticals. In Europe, black walnut plays an important role not only in the production of wood and fruit, but also as an ornamental tree. It is the world's most famous allelopathic specie due to the substance juglone present in all parts of the black walnut tree (Willis 2000, Shibu, Hozmuller 2008, Montecchio & Faccoli 2014, Juhásová & Hrubík 1984, Stoić *et al.* 2016).

In addition, due to its favourable aesthetic properties and significant phytocide activity, as well as its high content of repellent substances, it is well used in horticulture and landscaping. Thanks to its powerful root system, black walnut is very resistant to wind. This fact therefore predisposes it to be planted in open habitats, where it could function as a stabilizing part of windbreaks with the other trees such as summer oak, heart linden, milk maple, etc. (Blažejová, Pástor & Martiník 2020, Kremer *et al.* 2008). Another of its advantages is the low level of attack by animal pests, while animals do not cause such significant damage to this tree as to the other trees (Tokár & Krekulová 2005, Juhásová & Hrubík 1984). Black walnut fructifies relatively early, often, and abundantly. Its fruits are used in the food industry for the production of ice creams, desserts and liqueurs, but also as feed for exotic birds. Black walnut also has antiseptic astringent effects, which is used in the pharmaceutical industry. The sought-after tincture is made from the fruits, but also jewellery and the shells can be used as fuel due to their high calorific value. While royal walnut is grown primarily for its fruits, black walnut is mainly used for the wood industry and for energy purposes. After thinning and from the branches of the extracted trees, the high-value and low-moisture wood chips are produced, which is a sought-after item for users of renewable energy sources. In the furniture industry and the woodworking industry, black walnut wood is sought-after and popular for its beautiful colour, high strength, and durability. It does not curl when drying, is easy to work with and withstands weather conditions. The minimum price of log is currently 400 Euro per m^3, on the Austrian market it is from 480 to 1,650 Euro per m^3. Lumber is sold from EUR 1,200 per m^3. The highest quality logs for veneer production are sold at auctions (Ondrejka *et al.* 2019).

The main aim of the paper is the investigation and soil-ecological conditions identification of black walnut for potential planting and cultivation in agroforestry systems in Slovakia. The fulfillment of this task presupposes the establishment areaof pilot research-demonstration plot for detection and verification of the natural conditions of black walnut in cooperation with practitioners. This became as a basis for the compilation of synthetic map of the suitability for growing black walnut processed by GIS tools on the BPEJ database. It allows current modification of national legislation that facilitates the development of methodology of agroforestry systems implementation in Slovakia in accordance with the European Union legal order.

MATERIAL AND METHODS

Firstly, there is a need to investigate the production-ecological aspect of the trees potentially used for agroforestry systems which can be planted, e.g., with permanent grasslands in combination with grazing livestock or as an arable land combined with the cultivation of conventional agricultural crops, etc. There are many examples of the utilization of the black walnut in agroforestry, e.g., Šálek *et al.* (2012), Vacek *et al.* (2009), Pástor & Nováková (2017 a, b), Scott & Sullivan (2007). Moreover, agroforestry farmers can diversify their production, reduce some costs, and achieve better productivity (Bakay & Pástor 2015, Gergeľ *et al.* 2020, Hrib *et al.* 2017, Nicolescu *et al.* 2020, Vacek *et al.* 2009).

Black walnut (*Juglans nigra* L.) is a fast-growing hardwood. In a good location, a tree in its 25th year reaches a height of 25-32 meters and a trunk thickness of around 45 cm, which is an average increase of approximately 6 cm in circumference per year. In thickets, it creates a straight trunk with a high crown. The growth slows down in 25-30 years and the average life expectancy is 250-300 years. The average annual height growth until the period of rapid growth (25 years) is 1.2 meters. Compared to the royal walnut (*Juglans regia* L.), it has more modest habitat requirements, especially soil conditions. It is more resistant to frost as adult individuals tolerate winter frosts down to -35°C very well. It has a better decomposition of waste and provides very valuable wood material. This predisposes this tree to the cultivation even in the worse soil and climatic conditions of Slovakia.

The database of soil-ecological evaluation units (BPEJ © VÚPOP Bratislava) was applied for the map of sustainability black walnut compilation. This database which implicitly includes a vector layer, was developed at a scale 1: 5,000 and digitized in 1993 as polygonal vector layer in ESRI Shape, with a total of approximately 8,000 individual types of BPEJs (Džatko & Sobocká 2009). The BPEJ vectorised database presents an important tool used at the national level for several purposes, such as: assessment of the soil quality of agricultural land, legislative protection of soils, spatial planning, land take legislation, land consolidation, re-cultivation measures and others.

The soil-ecological evaluation unit (BPEJ) represents a quasi-homogeneous spatial unit expressed by a 7-digit code (Figure 1) which involves the climate-soil-topography components: climate region, soil type, slope + exposure, stoniness + soil depth, and soil texture.

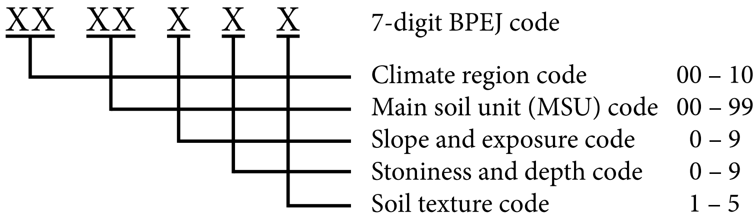

Figure 1 Structure of the BPEJ code

In terms of processing georeferenced databases, the updated tools of GIS products were used: GIS tools, commercial product ArcMap Version 9.3 f. ESRI. Determined areas were calculated as overlapping vector layers to produce final map of the spatial distribution. Areas of the sustainability of the black walnut were ranked:

1. very suitable
2. moderately suitable
3. non-suitable

As the pilot research-demonstration plot was selected a black walnut plantation in south part of central Slovakia in Kosihy nad Ipľom.

RESULTS AND DISCUSSION

By detailed study of soil-ecological demands for the black walnut growth requires:

Climate: in its homeland, it grows in climatic conditions with an average rainfall of approximately 800 mm per year. In the parts where the precipitation is lower, the moisture deficit is compensated by the groundwater in the floodplains. It is frost-resistant tree that can be grown down to -35°C. It blooms approximately 14 days after the walnut tree, so it is less damaged by spring frosts.

Soil: predominantly humus, loamy and deep soils that are well supplied with water. Although undemanding to the quality of the soil, it thrives in permeable, moist habitats. Even dry soils do not interfere with it, but in the first years it requires copious watering.

Location: it requires sunny locations and at the same time does not tolerate competition from other trees. It is resistant to wind. Suitable locations can be not only lowlands, but also mild hills up to 400 m above sea level are suitable in our conditions with an average annual temperature above 8°C. It does not belong to the invasive trees and has no negative effects on ecosystem. It can be grown not only in forest stands but can also be beneficial in agroforestry systems. The reason for this is its rapid growth, it is a light-loving tree that seeks light near other trees.

Soil survey, soil sampling and recognition of the soil profile in the area of Kosihy nad Ipľom were carried out in November 2022. The village is located in the Ipeľská kotlina (basin). The altitude in the centre of the village is 140 m above sea level, and other areas are 133–236 m above sea level. The southern part of the district is on the wet flooded floodplain and Ipeľ terraces with sand overflows, the northern part is on a hilly land with flat ridges cut from Early Tertiary deposits. It is forested with oak only on the slopes. Alluvial soils predominate.

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Date: 14. 11. 2022
Locality: Kosihy nad Ipľom, county Veľký Krtíš
Weather: air temperature 6 °C, clouded, intermittent rain
Height above sea level: 138 m
Sloppiness, exposure: plain, floodplain of the river Ipeľ
Ground water level: 2 m
Current use: orchard, planting of black walnut with a clip of approx. 5 m

Soil taxonomy (MSCS 2014): Kultizem Gleyic (KT_G) with buried horizon unsaturated, clayey-oamy, garden form, on fluvial sediments.

Soil profile description:

Akj($_G$) (0-40 cm) – cultivated amelioration horizon, colour 10YR 4/2, loamy (30-45 % particles <0.01 mm), fine-granular structure, wet, plastic, slight signs of greying, strong biological life and rooting, sharp transition to

C(G) (40-50 cm) – parent material alluvial sediment, colour 2,5Y 5/2, clayey-loamy, granular structure, wet, plastic, presence signs of gleying moderate biological life, sharp transition to

Am1b (>50 cm) buried humus colour 10YR 4/1, clayey-loamy, granular structure, wet, plastic.

Figure 2 Description of the soil profile

The soil profile was evaluated and classified according to the Morphogenetic Soil Classification System of Slovakia (Societas pedologica slovaca 2014).

Figure 3. Location of the area of Kosihy nad Ipľom (black walnut planting)

Table 1
Soil laboratory analyses of the soil profile in 3 samples (982, 983, 984)
Sample No. 982 (Kosihy nad Ipľom 0 – 35)

Soil properties	Value	Measure	Content evaluation	Method
pH/KCl	6.34	–	Slightly acid	STN ISO 10390
$N_{anorg.}$	2.11	mg/kg	Very low	Continuous flow analyser
Cox	1.85	%	High	Walkey-Black
Humus	3.18	%	Strongly humose	Recalculation
Carbonates	<0.05	%	Very slightly calcareous	Janko's lime meter
P Phosphorus)	369	mg/kg	Very high	Continuous flow analyser
K (Potassium)	684	mg/kg	Very high	Zbíral: Soil Analysis I. (Mehlich III)
Mg (Magnesium)	418	mg/kg	Very high	Zbíral: Soil Analysis I. (Mehlich III)
Texture F1 (2 – 0,25mm)	9.233	%	–	Pipetting method according to Novák
Texture F2 (0,25 – 0,05 mm)	12.83	%	–	Pipetting method according to Novák
Texture F3 (0,05 – 0,01mm)	38.285	%	–	Pipetting method according to Novák
Texture F4 (0,01 – 0,001 mm)	20.468	%	–	Pipetting method according to Novák
Texture F5 (<0,001 mm)	19.184	%	–	Pipetting method according to Novák

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Sample No. 983 (Kosihy nad Ipľom 35 – 45)

Soil properties	Value	Measure	Content evaluation	Method
pH/KCl	6.38	–	Slightly acid	STN ISO 10390
$N_{anorg.}$	4.5	mg/kg	Very low	Continuous flow analyser
Cox	0.87	%	Low	Walkey-Black
Humus	1.5	%	Moderately humose	Recalculation
Carbonates	0.1	%	Very slightly calcareous	Janko's lime meter
P (Phosphorus)	234	mg/kg	Very high	continuous flow analyser
K (Potassium)	505	mg/kg	Very high	Zbíral: Soil Analysis I. (Mehlich III)
Mg (Magnesium)	461	mg/kg	Very high	Zbíral: Soil Analysis I. (Mehlich III)
Texture F1 (2 – 0,25mm)	3.623	%	–	Pipetting method according to Novák
Texture F2 (0,25 – 0,05 mm)	11.68	%	–	Pipetting method according to Novák
Texture F3 (0,05 – 0,01mm)	39.47	%	–	Pipetting method according to Novák
Texture F4 (0,01 – 0,001 mm)	22.738	%	–	Pipetting method according to Novák
Texture F5 (<0,001 mm)	22.489	%	–	Pipetting method according to Novák

Sample No. 984 (Kosihy nad Ipľom 35 – 45)

Soil properties	Value	Measure	Content evaluation	Method
pH/KCl	6.35	–	Slightly acid	STN ISO 10390
$N_{anorg.}$	0.957	mg/kg	Very low	continuous flow analyser
Cox	1.39	%	moderate	Walkey-Black
Humus	2.4	%	Moderately humose	Recalculation
Carnonates	0.1	%	Very slightly calcareous	Janko's lime meter
P Phosporusr)	241	mg/kg	Very high	continuous flow analyser
K Piotassium)	534	mg/kg	Very high	Zbíral: Soil Analysis I. (Mehlich III)
Mg (Magnesium)	547	mg/kg	Very high	Zbíral: Soil Analysis I. (Mehlich III)
Texture F1 (2 – 0,25mm)	4.955	%	–	Pipetting method according to Novák
Texture F2 (0,25 – 0,05 mm)	14.114	%	–	Pipetting method according to Novák
Texture F3 (0,05 – 0,01mm)	31.674	%	–	Pipetting method according to Novák
Texture F4 (0,01 – 0,001 mm)	24.525	%	–	Pipetting method according to Novák
Texture F5 (<0,001 mm)	24.732	%	–	Pipetting method according to Novák

According to the laboratory analyses, the soil profile is slightly acidic, with a very small supply of mineral nitrogen, with a high content of carbon and humus in the surface horizon, below it is moderately humose, with a high supply of nutrients (N, P, K, Mg, Ca). The profile is loamy, deeper clay-loamy, non-carbonate.

As soil profile was classified Kultizem Gleyic (KT_G) with buried horizon unsaturated, clayey-loamy, garden form, on fluvial sediments. Basic diagnostics is soil with cultivation melioration diagnostic Akj horizon more than 35 cm thick with signs of gleyic G horizon. Soil type is core of each soil ecological units which is included in the 7-digit BPEJ code as the main soil unit (Džatko & Sobocká 2009).

In order to create a GIS layer of soil blocks suitable for growing black walnut in agroforestry systems in Slovakia, it was necessary to identify and develop an analysis of the demands of black walnut on the soil, geomorphological and climatic conditions of the environment.

Table 2

Main soil units (BPEJ) considering suitability agro-ecological conditions of the black walnut

Main soil unit in the BPEJ (Džatko & Sobocká, *et al.* 2009)		
Very suitable	**Moderately suitable**	**Non-suitable**
01, 02, 03, 06, 07, 08, 09, 11, 12, 17, 18, 19, 20, 22, 23, 25, 26, 32, 33, 36, 37, 39, 44, 45, 46, 48, 74	04, 05, 13, 14, 15, 16, 21 – 27, 28, 29, 30, 31, 34, 35, 38, 40, 41, 42, 43, 47, 49, 50, 51, 52, 53, 54, 55, 56, 85, 88	10, 57, 58, 59, 75, 76, 77, 78, 79, 80, 81, 82, 83, 84, 86, 87, 89, 00

Table 3

Sloppiness + exposure (BPEJ) considering suitability agro-ecological conditions of the black walnut

Sloppiness + exposure in the BPEJ (Džatko & Sobocká, *et al.* 2009)		
Very suitable	**Moderately suitable**	**Non-suitable**
0, 1	2, 3	4, 5, 6

There is a need to mention that at skeleton and soil depth the same codes were applied as in Tab. 3.

Table 4

Soil texture (BPEJ) considering suitability agro-ecological conditions of the black walnut

Soil texture in the BPEJ (Džatko & Sobocká, *et al.* 2009)		
Very suitable	**Moderately suitable**	**Non-suitable**
2, 5	3	1, 4

As a result, the Map of agricultural land suitable for walnut plantation in Slovakia was created (Figure 4).

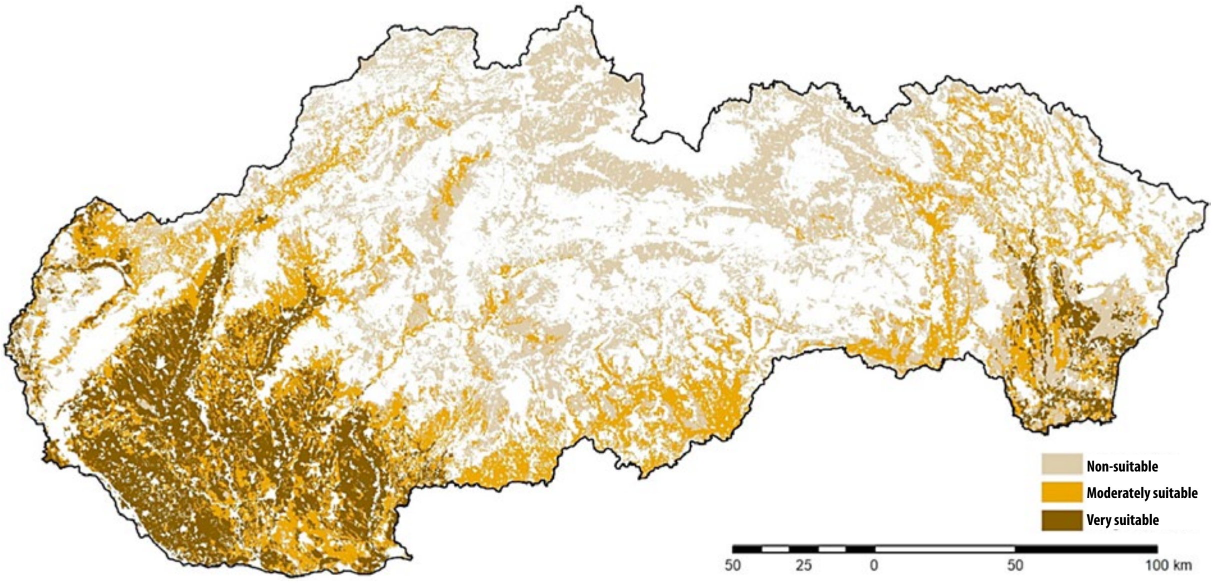

Figure 4 Agricultural land suitable for walnut plantation in Slovakia

The area of individual categories is shown in the following Table 5.

Table 5

Acreage of area diversified according to agro-ecological suitability

Suitability	**Black walnut/m²**	**Black walnut/ha**	**Percentage**
Non-suitable	11529759465.178300000	1 152 975.95	45.3%
Moderately suitable	8129817262.293090000	812 981.73	31.9%
Very suitable	5820425513.207530000	582 042.55	22.8%
Total:	25480002240.678900000	2 548 000.22	100%

Black walnut grows to a lesser extent in forest stands and can occur in gardens and parks. Creation of the interlinkages within agroforestry systems is very complex process. A particular attention is placed on multiple-purpose trees or perennial shrubs. To be a component of agroforestry system there was necessary to know the pedo-climatic requirements of the surrounding environment (habitat).

The analysis of the results showed that the most suitable locations for planting black walnut represent an area of approximately 23%, and approximately 32% are moderately suitable areas. These locations are related to Fluvizem, Chernozem and Mollic Fluvisol soil types occurred in the lowland and hilly areas of southwestern Slovakia, less in the Eastern-Slovak lowland. Moderately suitable locations include the areas of the southern central Slovakia, partly in lower basins. As we mentioned, black walnut is not demanding specific conditions, therefore its planting is recommended on 55% of agricultural land.

This approach can be applied for the other trees (like chestnut, *etc.*) shrubs and grasses.

CONCLUSIONS

The utilization of black walnut in agroforestry systems in Slovakia needs solve an identification of areas in agricultural land suitable for its optimal cultivation. Also, its potential to be part of agroforestry systems in the framework of sustainable management needs to be re-assessed and implemented. For example, black walnut can be very interesting and promising commodity for agro entrepreneurs, both in terms of fruit production and high-quality wood that is well benefited on the market.

A map of the suitability for cultivation of black walnut in terms of agro-ecological conditions is presented. The reason for this is to investigate the potential of black walnut for cultivation in the conditions of agroforestry systems.

The suitability analysis showed a relatively large potential for the cultivation of black walnut in Slovakia. The areas delimited using GIS tools and BPEJ databases confirmed that the areas very suitable for cultivation represent 610,000 ha whereas the areas moderately suitable are on 765,000 ha.

The purpose of our contribution is to support and develop methodological guidelines for the establishment of agroforestry systems in Slovakia. In addition, this contribution will support the application of new legislation for agroforestry in the conditions of Slovakia.

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