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Assessment of Agricultural Areas Suitable for Agroforestry in Latvia

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Abstract: The role of trees on agricultural land is predicted to increase rapidly in order to achieve biodiversity, environmental, and climate goals. This study demonstrated the selection and evaluation approach and assessed the suitable agricultural land for agroforestry practices in hemiboreal Latvia, which was selected as the demonstration area by synthesizing knowledge of environmental sciences, remote sensing, and relevant legislation on land use and management. The total area of agricultural land suitable for agroforestry was estimated to be 14.1% of the total agricultural land in Latvia (351.5 kha). The selected agricultural land mainly comprised semihydromorphic soils; the dominant soil texture was loamy sand. Current dominant land use in the selected agricultural land consisted of heterogeneous agriculture and pastures; however, the selected agricultural parcels were outside intensive agricultural production for the most part—only 0.38% of the total selected agricultural land was accepted to receive state support and/or EU support to farmers under the Common Agricultural Policy (CAP). Considering the lengthy process of implementation of new agricultural-land-management practices, as well as taking into account the ambitious timeframe for reaching biodiversity, environmental, and climate goals, we recommend reducing hindrances to the introduction of agroforestry systems. The provided selection and evaluation approach is transferable to other countries and regions by adaptation of the elaborated methodologies to available country-specific spatial information and data

Keywords: agroforestry; agricultural land; trees; hemiboreal zone; climate change mitigation

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1. Introduction

As land-use change to agricultural land and intensive agricultural production is still listed as one of the pressures on the environment and climate [1,2], including soil ecosystem services (ESs) [3,4], the need for the improvement and diversification of current agricultural-land-management practices simultaneously aimed at climate-change mitigation, enhancing biodiversity, and improving soil and water quality is increasing. To address these environmental problems at the global level, the goals of the 2030 Agenda for Sustainable Development, adopted by all United Nations Member States in 2015, include climate actions to combat climate change and its impacts, as well as life and land goal aimed to protect, restore, and promote the sustainable use of terrestrial ecosystems [5]. The European Commission has adopted packages of proposals and issued policies, strategies, and legislation such as the Water Framework Directive (Directive 2000/60/EC), the European Union (EU) Biodiversity Strategy for 2030 (COM(2020) 380 final), the Common Agricultural Policy 2023–2027, the Paris Agreement contributed by the EU's Effort Sharing 2021–2030 (Regulation (EU) 2018/842), and The European Green Deal in recent decades. Furthermore, in March 2022, EU leaders in the European Council agreed to phase out Europe's dependency on Russian energy imports (REPowerEU Plan) as soon as possible [6]. Consequently, requirements for domestic bioenergy will significantly increase to saturate local and export markets. A significant increase in forest biofuel price (16% on average and 27% for pellets) in the first half of 2022 in comparison to 2021 (according to the market analysis report [7]) increased the economic attractiveness of wood resources from short-rotation forests (SRFs) and short-rotation coppices (SRCs). At the same time, most of the tree plantations in Europe established during the last thirty years with EU support (targeted subsidies for the afforestation of former agricultural lands) are close to or even above the minimum permanence period [8]. There, the previous land use (i.e., croplands) will likely be restored, negating the investments in carbon (C) sequestration and reducing the supply of many other ESs [8]. This highlights the need for a new and clear national- and European-level strategy, especially given that there is relatively little time left to achieve the 2030 targets with regard to a targeted change in land-management practices.

Agroforestry, in the context of this study, refers to the integrated land-use systems and practices in which woody perennials are grown on croplands or grasslands in combination with agricultural crops on the same land management unit [9–13]. Agroforestry has become a strategic instrument worldwide, including in Europe, with which to progress toward achieving ambitious environmental, climate, and energy independence goals [1,14–19]. At the same time, agroforestry provides the benefits of economic development [20,21]. A wider implementation of agroforestry practices in agricultural landscapes would still ensure multiple agricultural products (food and/or fodder), while simultaneously moderating concentrations of greenhouse gases (GHGs) in the atmosphere and undesirable impacts on soil, water, and biodiversity [1,14,22–27], as well as improving domestic woody biomass availability for energetic purposes [28]. Overviews of ES and environmental benefits provided by agroforestry systems (for instance, see References [29–31]) highlight both provisioning and regulation and maintenance ES, as well as cultural ES. In Europe, agroforestry has been recognized as one of the most important tools with which to mitigate and adapt to climate change [15,26]. However, ambiguous research results have also been observed—for instance, the latest meta-analysis showed no unequivocal effect of European agroforestry on biodiversity [32].

Although agroforestry is a historical element of European landscapes [22,32], the degree of implementation of modern agroforestry systems in Europe has been quite low to date [22,33], and mostly practiced in marginal areas to improve sustainability in the short term [34]. Furthermore, these marginal areas are characterized by having topography, low soil fertility, and a climate unfavorable to intensive agriculture [31,35]. Nevertheless, the latest international policies, strategies, and plans have emphasized that the role of trees in agricultural land and other lands outside the forests will increase [36]. Few recent European-level assessments have been conducted to evaluate the total area of particular agroforestry systems (e.g., References [26,35,37]) and to estimate agroforestry potential in Europe (e.g., Reference [38]), focusing specifically on arable and grassland areas already under environmental threat. For instance, Mosquera-Losada et al. (2018) calculated that total agroforestry practices (including silvopasture, silvoarable, home-garden practices, riparian buffer strips, and hedgerows) cover 19.77 million hectares in Europe; furthermore, silvopasture practice covers the largest area—over 17.77 million hectares [26]. Plieninger et al. (2015) reported that the total area of wood-pasture—including pastures in open woodland and pastures with sparse trees and cultivated trees—in the 27 EU member states was 203,367 km^2 [35]. Reisner et al. (2007) estimated that target regions for silvoarable agroforestry in Europe where productive growth of trees in silvoarable agroforestry systems could be expected to simultaneously reduce the risk of soil erosion and nitrate leaching and increase landscape diversity made up about 40% of arable European land [38].

In Latvia, agroforestry is not defined under national legislation, nor is it supported by the Common Agricultural Policy (CAP) mechanisms and targeted subsidies, thus far. Currently, under Latvia's CAP Strategic Plan for 2023–2027, the allowable agroforestry elements on agricultural lands are no more than 50 individual growing trees per hectare in cropland. In terms of biodiversity, EU grassland biotopes (e.g., 5130 and 6530*) where the overlapping of forest (including juniper and heather) and grassland ecosystems is one of the main characteristics are defined as agroforestry, as well [39]. Nevertheless, the results of the estimate of tree cover on agricultural land showed that, across seven countries in Europe (Austria, Switzerland, Estonia, Latvia, Lithuania, Sweden, and Norway), Latvia has the largest extent of agricultural land with significant tree cover—about 22.4% of agricultural land (631 kha) has more than 10% tree cover, and about 18.7% of the agricultural area (527 kha) has more than 20% tree cover [37]. According to Plieninger et al. (2015), wood-pastures in Latvia cover a total of approximately 950 km^2 (1.5% of the total country area), with roughly 848 km^2 being pastures with sparse trees and 102 km^2 pastures in open woodlands [35]. Furthermore, in a Europe-level assessment, Latvia was identified as a potential productive wild-cherry-tree-growth area on arable land to increase landscape diversity [38].

Although agroforestry has a long tradition in boreal and hemiboreal regions (examples include reindeer husbandry, grazing of wood pastures, buffer strips, scattered trees in agricultural land, and others), the implementation of modern agroforestry systems in boreal and hemiboreal regions remains quite rare. Furthermore, there is also a lack of region-specific information on suitability of agricultural land for agroforestry considering multiple aspects, including legislation on land use and management and distribution of agricultural land suitable for agroforestry, including characteristics of soil types and texture and current land use. The objective of this study was to demonstrate the selection and evaluation approach, as well as to assess the suitable agricultural land for agroforestry practices in hemiboreal Latvia (selected as demonstration area) by using a transdisciplinary approach synthesizing knowledge of environmental sciences, remote sensing, and national and EU legislation on land use and management.

2. Materials and Methods

The study was conducted in Latvia, which belongs to the hemiboreal zone [40]. The study covered the area of the whole country: 6458.9 kha, including 1034.7 kha grassland and 1465.2 kha cropland [41]. A map of distribution of land use in Latvia is provided in Appendix A (Figure A1). The study was conducted by using geospatial methods in the QGIS 3.22 environment. To be able to process data at a national scale, all geospatial layers were processed in separate 50 × 50 km tiles, based on the tks93_50000 geospatial data layer from the GisLatvija 10.2 database [42].

In Latvia, all agricultural lands are assigned a land-quality value in points from <10 to >60 (maximum 85), depending on the quality assessment of land by the regulatory productivity (Figure 1). One land-quality-value point equals 70 kg of rye units (production) according to the Republic of Latvia Cabinet Regulation No. 103 'Regulations Regarding Mass Appraisal' (adopted 18 February 2020); the average land-quality value of agricultural lands in Latvia is 38 points [43]. Land fertility in agricultural land parcels with land-quality values equal to or less than 25 points are considered low [44–46], and the production of agricultural crops is not cost-efficient in these parcels. Thus, to select suitable land parcels for agroforestry systems, first we selected agricultural land parcels where the land-quality value was relatively low—equal or less than 25 points. Our basic assumption is that agricultural land parcels with land-quality values equal to or less than 25 points could increase in economic value as a result of agroforestry practices.

The next steps included the exclusion of land parcels with forest cover by overlapping the State Forest Service data layer and exclusion of protection zones around watercourses and roads, which are subject to the Protection Zone Law [47]. Respectively, 12 m–wide buffer strips around the axis of the ditches (distance was measured from the central axis; it was assumed that the average width of ditches is 4 m) and 10 m–wide buffer strips along the other watercourses and roads (distance was measured from the edge of the bank of the river, coastline, or road) were excluded from further analysis. Thus, selected suitable agricultural land for agroforestry consists of agricultural land parcels with land quality value $\leq$ 25 points, excluding areas with forest cover and buffers (protection zones) around watercourses and roads. The spatial-data-processing framework is shown in Figure 2, which represents our workflow for selecting suitable land parcels for agroforestry systems (agrisilvicultural and agrosylvopastoral systems).

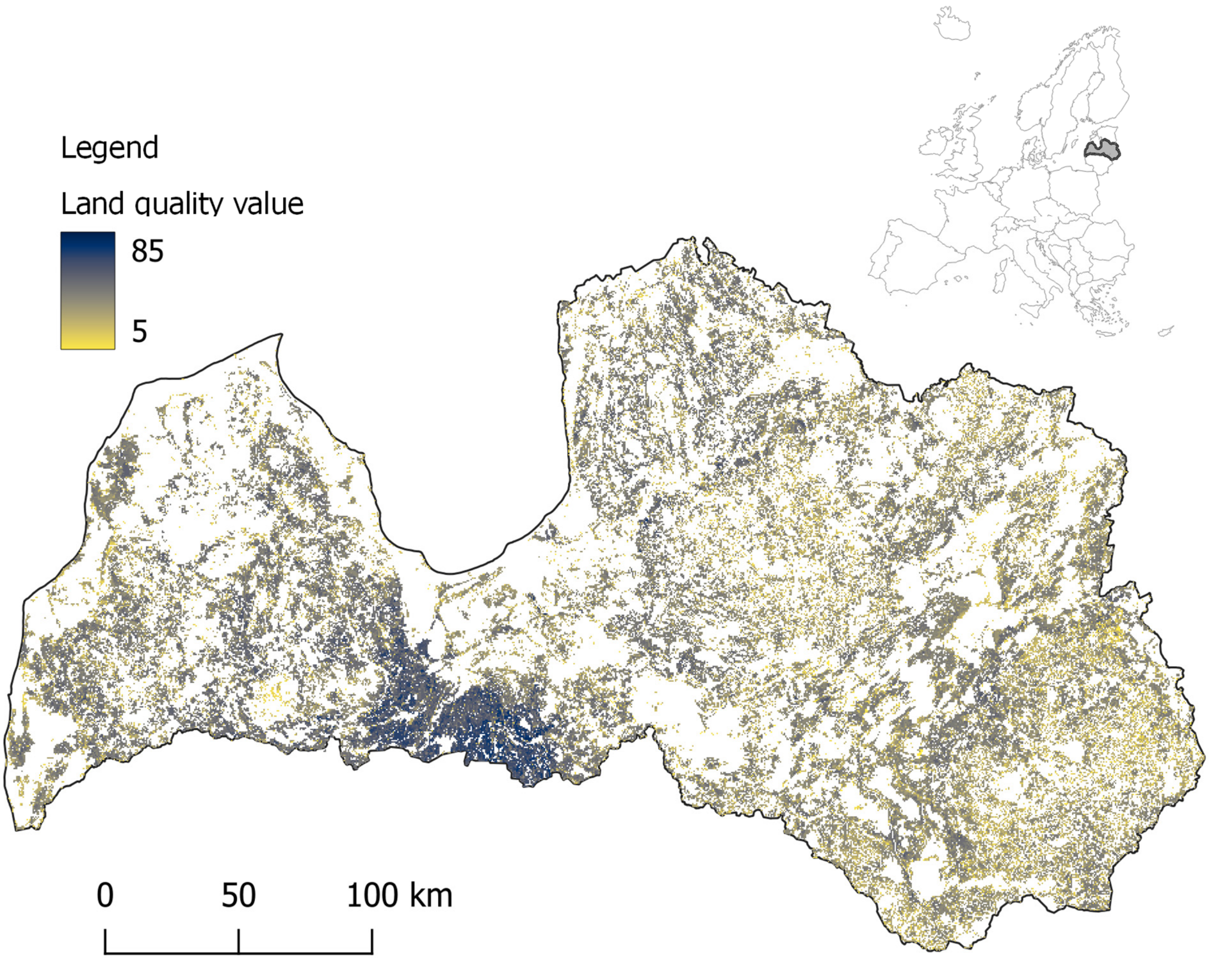

Figure 1. Distribution of land-quality values of agricultural land in Latvia.

The resulting spatial data layers were then overlapped with data from various sources that represented soil properties, vegetation and crop cultures, land-cover type, land-amelioration information, and quaternary sediments. References to various used data sources are represented in Table 1.

The initial results of the spatial data analysis were further processed and analyzed in the R environment (R version 4.0.3; RStudio version 1.3.1093). Figure 1, Figure 3 and Appendix A Figure A1 were prepared by using QGIS 3.22.5, and Figures 4–8 were prepared with the R package 'ggplot2' and 'ggbreak' [48].

The scale and varying spatial resolution of the input data form the uncertainty of geospatial data (the study results reflecting areas of suitable agricultural land for agroforestry practices). No alternatives for locally sourced data with equivalent or better resolution were available, but the existing geospatial data and their uncertainty and accuracy were completely satisfactory for this study (both to demonstrate the selection and evaluation approach, as well as to assess the suitable agricultural land for agroforestry practices in Latvia).

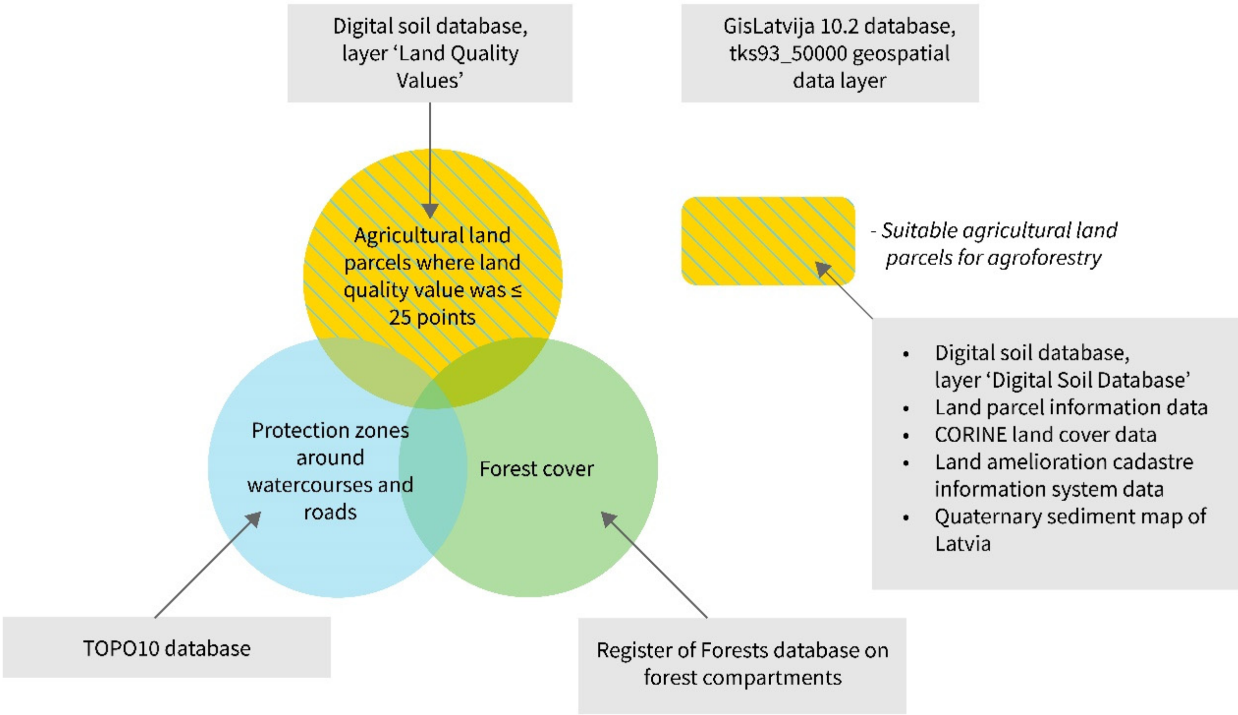

Figure 2. Concept for selecting and characterizing agricultural land parcels suitable for agroforestry (target region) in Latvia (spatial-data-processing framework).

Table 1. Geospatial data layers used to select and characterize agricultural land parcels suitable for agroforestry in Latvia.

Geospatial Data Layers	Provided Information	Reference
GisLatvija 10.2 database, tks93_50000 geospatial data layer (scale 1:50,000)	Map tiles for data processing	Ltd Envirotech; Central Statistical Bureau, Republic of Latvia
Digital soil database, layer 'Land Quality Values' (scale 1:10,000)	Information on agricultural land quality values in points (mapped during 1960–1991)	Ministry of Agriculture, Republic of Latvia
Digital soil database, layer 'Digital Soil Database' (scale 1:10,000)	Information on a year of mapping, soil texture and soil type	Ministry of Agriculture, Republic of Latvia
The State Register of Forests database on forest compartments	Polygon layer on all forest compartments in Latvia	The State Forest Service (Latvia)
Land parcel information data	Information on declared agricultural crops and accepted state support and/or EU support to farmers under the Common Agricultural Policy (CAP) provided by the Rural Support Service (in 2019)	The Rural Support Service (Latvia)
CORINE land-cover data (scale 1:250,000)	Polygon data with information on land cover in 44 different classes	Copernicus Programme
Land amelioration cadaster information system data	Spatial information on drainage and melioration objects.	Real Properties of Ministry of Agriculture, Republic of Latvia
Quaternary sediment map of Latvia (scale 1:200,000)	Information about spatial distribution of quaternary sediments in Latvia	State Geology Service (Latvia)
TOPO10 database	Information on road surface type of use and width class (layer road_L); Information on watercourses (lauer hidro_L)	Latvian Geospatial Information Agency (Latvia)

3. Results

3.1. Area of Suitable Agricultural Land for Agroforestry

We identified 431.8 kha of agricultural land with a land-quality value $\leq$ 25 points in Latvia. The highest proportion of agricultural land with land-quality value $\leq$ 25 points from the total area across different statistical regions of Latvia was identified in Latgale (12.2%), followed by Vidzeme (6.3%) (Figure 3). The total area of agricultural land where agroforestry could provide a solution for more effective land management (i.e., agricultural land with land-quality value $\leq$ 25 points, excluding areas with forest cover and buffers (protection zones) around watercourses and roads) was estimated to be 351.5 kha (14.1% of the total agricultural land in Latvia) including 306.6 kha of area without underground drainage systems (Figure 3). Almost half of the selected area (46% of the total selected area and 45% of the selected area without underground drainage systems) corresponded to land-quality values of 21–26 (Figure 4). The highest proportion of agricultural land where agroforestry could provide a solution for more effective land management from the total area across different statistical regions of Latvia was identified in Latgale (9.1%) followed by Vidzeme (4.4%).

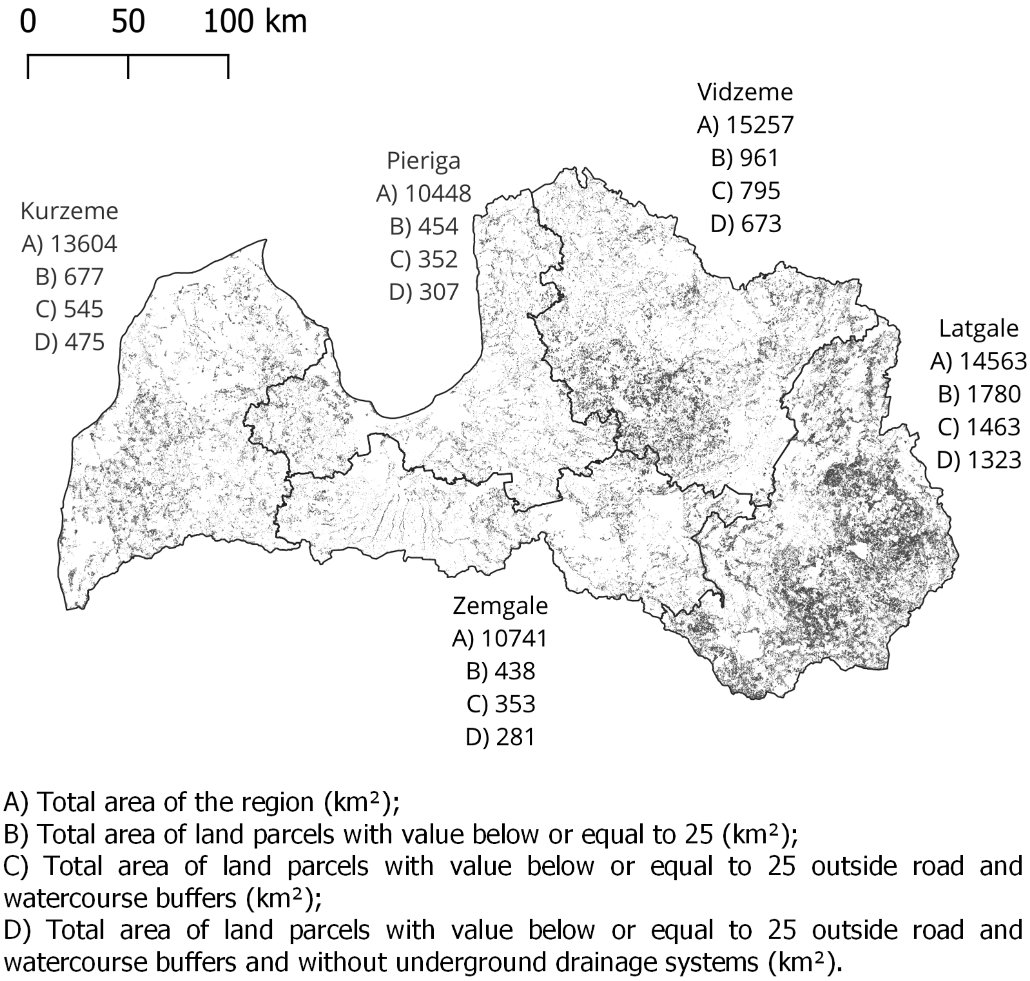

Figure 3. Distribution of agricultural land parcels where agroforestry could provide a solution for more effective land management across different statistical regions of Latvia (Kurzeme, Pieriga, Zemgale, Vidzeme, and Latgale). Gray areas on the map of Latvia correspond to the D (total area of agricultural land parcels with land-quality value $\leq$ 25 points outside the road and watercourse buffers and without underground drainage systems).

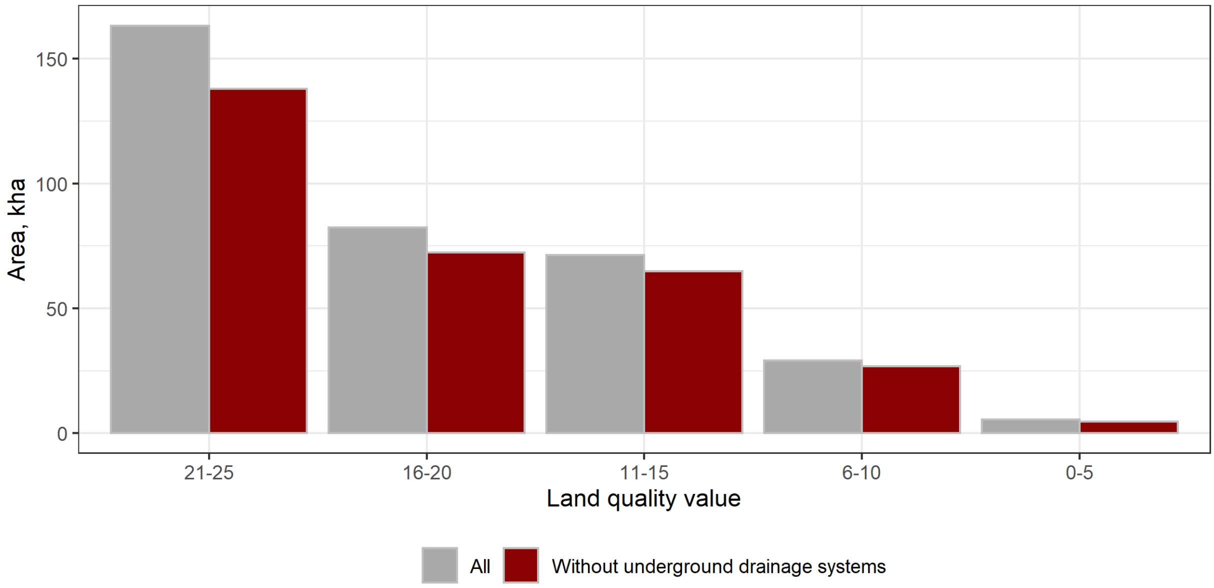

Figure 4. Area of low-value agricultural land parcels suitable for agroforestry by groups of land-quality values.

3.2. Soil Characteristics in Suitable Agricultural Land for Agroforestry

The largest part of the selected agricultural land on which agroforestry could provide a solution for more effective land management (49% of the total selected area and 48% of the selected area without underground drainage systems) corresponded to semihydromorphic soils (mostly podzolic–gley and gley soils) (Figure 5). The second-largest part of the selected area (38% of the total selected area and 41% of the selected area without underground drainage systems) corresponded to automorphic soils (mostly podzolic soils). In the group with hydromorphic soils (10% of the total selected area and 8% of the selected area without underground drainage systems), the dominant soil type was fen peat soil (Figure 5).

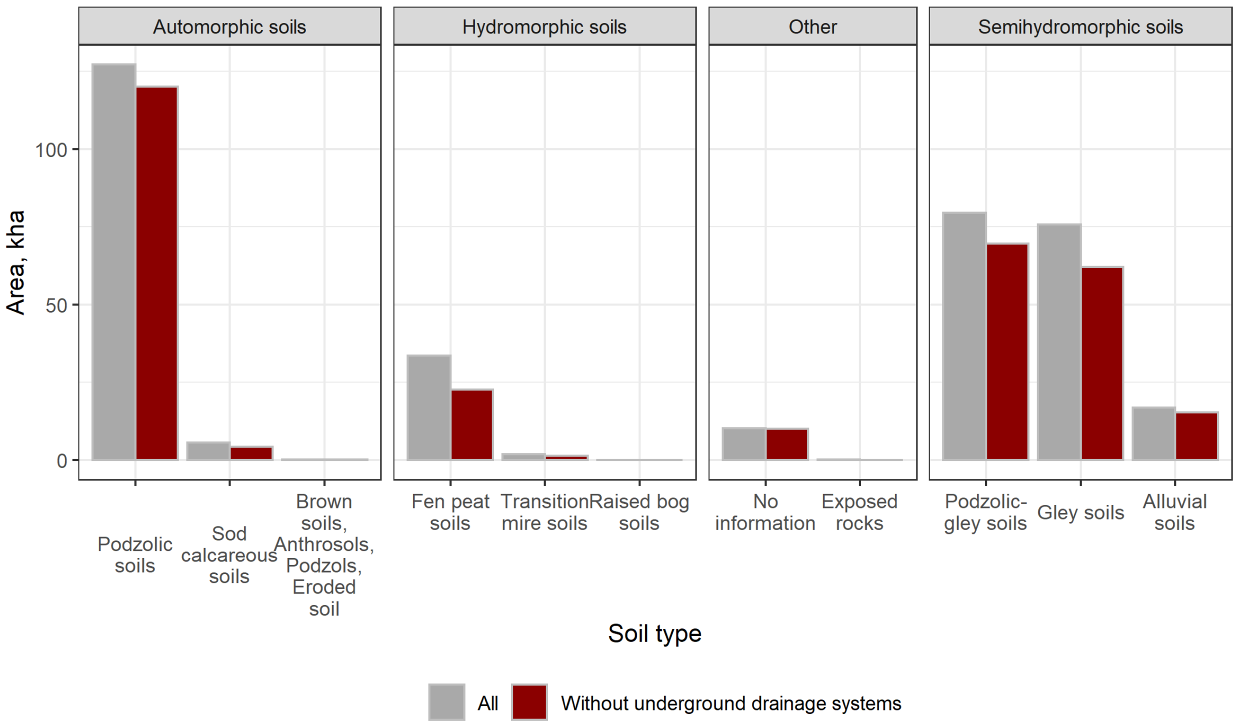

Figure 5. Area of low-value agricultural land parcels suitable for agroforestry by soil type.

The dominant soil texture [49] in the selected agricultural land suitable for agroforestry (Figure 6) was loamy sand (33% of the total selected area and 34% of the selected area without underground drainage systems), followed by loam (22% of the selected area), sand (20% of the total selected area and 21% of the selected area without underground drainage systems), and peat (9% of the total selected area and 7% of the selected area without underground drainage systems).

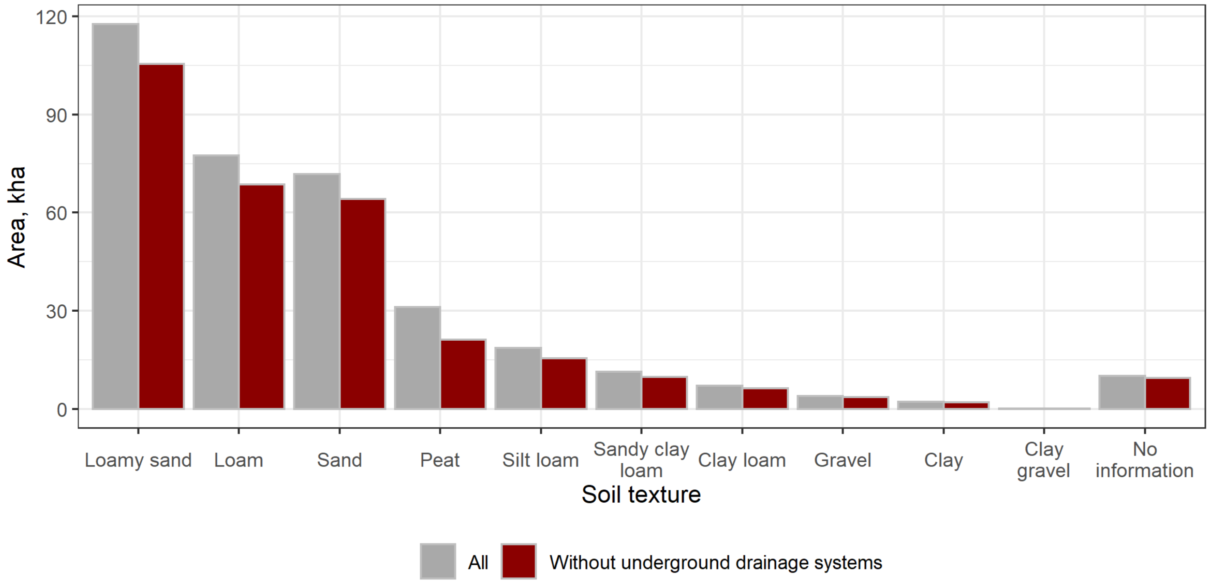

Figure 6. Area of low-value agricultural land parcels suitable for agroforestry by soil texture.

3.3. Current Land Cover in Suitable Land for Agroforestry

According to the CORINE land-cover data, the dominant current land use in the selected agricultural land suitable for agroforestry (Figure 7) consists of heterogeneous agricultural areas (36% of the total selected area and 38% of the selected area without underground drainage systems) and pastures (27% of the total selected area and 25% of the selected area without underground drainage systems), followed by transitional woodland/shrubs (12% of the total selected area and 13% of the selected area without underground drainage systems).

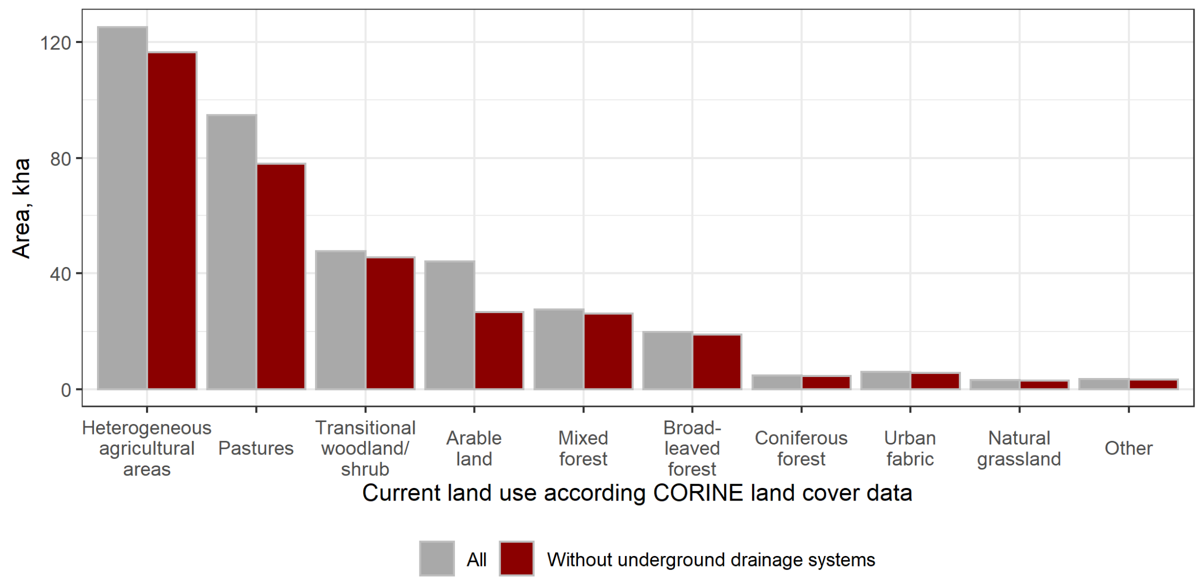

Figure 7. Area of low-value agricultural land parcels suitable for agroforestry by current land use according to the CORINE land-cover data.

The total area of agricultural land suitable for agroforestry for which cultivated agricultural crops were declared under the Rural Support Service (responsible for the implementation of a unified state support policy in Latvia) is 1347.0 ha. The dominant currently cultivated type of agricultural crop (declared) is grasses (including perennial grassland), which cover 92% of the total area where cultivated agricultural crops are declared (Figure 8). The second most widely cultivated agricultural crop on agricultural land suitable for agroforestry is cereals (5% of the total area where cultivated agricultural crops are declared).

In terms of financial support, 1344.3 ha or 0.38% of the total area of agricultural land suitable for agroforestry had been approved for state and/or EU support to farmers under the CAP provided by the Rural Support Service. The most common type of support was a combination of the Single Area Payment and support to Organic Farming (accepted for 1009.6 ha or 75% of the total area that had received at least one form—state or EU—of support).

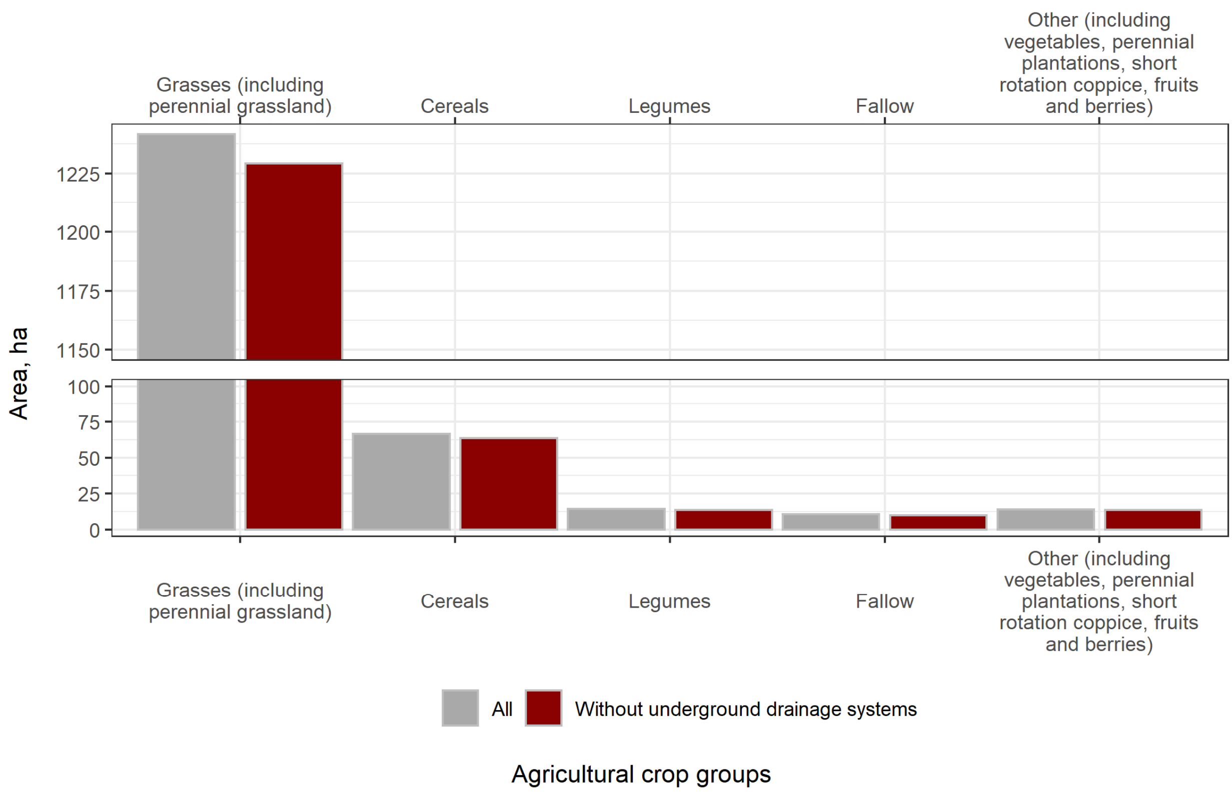

Figure 8. Area of low-value agricultural land parcels suitable for agroforestry by groups of currently cultivated agricultural crops (declared under the Rural Support Service).

4. Discussion

Interest in agroforestry systems has risen worldwide, and benefits provided by agroforestry practices are becoming more widely accepted based on conclusions of scientific research [27,50]. Nevertheless, the adoption and implementation of modern agroforestry practices remain low [27], especially in boreal and hemiboreal regions. To demonstrate agroforestry opportunities, we provided the selection and evaluation approach of suitable agricultural land for agroforestry practices in hemiboreal Latvia based on national-scale remote-sensing data. These data have a higher resolution and contain more detailed information compared to data such as the Land Use/Cover Area frame Survey (LUCAS) data, CORINE land-cover map, and Pan-European Land Cover Monitoring (PELCOM) map often used for a large-scale (for instance, EU-level) assessments of agroforestry systems and estimates of agroforestry potential [26,35,37,38]. Although the study covered only Latvia as a demonstration area representing the hemiboreal region, the provided selection and evaluation approach is transferable to other countries and regions by adaptation of the elaborated methodologies to country specific spatial data, since the LiDAR point cloud data are available in sufficient resolution for most of the European countries; however, the data specifications differ and require adaptation.

We identified agricultural land suitable for agroforestry (in total 351.5 kha, including 306.6 kha without underground drainage systems) in all statistical regions of Latvia. The highest proportion of agricultural land suitable for agroforestry from the total area across the different statistical regions was identified in Latgale (9.1%), which had fewer croplands historically and more pastures and dairy farms. Currently, only 0.38% of the total selected agricultural land suitable for agroforestry has been declared under the Rural Support Service and approved to receive at least one of state and/or EU support to farmers under the CAP (mostly the Single Area Payment in combination with support for Organic Farming). This indicates that the selected agricultural land suitable for agroforestry is mostly outside intensive agricultural production, and landowners or land managers would very likely be interested in economically viable and cost-effective management of the selected areas. However, significant investments might be necessary to restore road and amelioration infrastructure and to remove existing vegetation, consisting mainly of low-value, sparse groups of trees and bushes. Additional complexity (when considering an area for agricultural production) is created by the small size and poor or periodic accessibility of these sites. In agroforestry systems (such as SRC), the role of these issues is considerably smaller since fields should be accessed only a few times during the rotation period and harvesting can be performed during winter, when the soil is frozen and the crops do not hamper access to fields.

In the Latvian context, the tree species suitable for growing on agricultural land that could potentially produce economically viable wood yield are silver birch (*Betula pendula* Roth) [51,52], hybrid aspen (*Populus tremuloides* Michx. X *Populus tremula* L.) [53,54], poplars (*Populus* spp.) and their hybrids [55], willows (*Salix* spp.) [56,57], grey alder (*Alnus incana*), black alder (*Alnus glutinosa* (L.) Gaertn.), hybrid alder [56,58], Scots pine (*Pinus sylvestris* L.) [59], European larch (*Larix decidua* Mill.) and its hybrids [60], wild cherry (*Cerasus avium* (L.) Moench), and small-leaved lime (*Tilia cordata* Mill.), which is also an important nectar plant in the region [59,61]. Some interest has also been shown in hazel and walnut trees (*Corylus* spp. and *Juglans* spp., respectively) mostly due to their fruits [62]; however, the northern and northeastern regions of Europe, for instance, are not recommended as productive growth areas for walnut trees [63]. Nevertheless, tree species for agroforestry systems have to be selected according to the suitability to soil type and texture, moisture, and other agroecological conditions, including nutrient status, and considering potential competition with agricultural crops. In soil that is less suitable for tree planting due to acidity, nutrient deficiency, and/or insufficient content of organic matter, fertilizers such as wastewater sludge, wood ash, digestate (a by-product of biogas production) and compost can be applied (see References [64,65]), simultaneously promoting the implementation of bioeconomic principles. Landowners and land managers have certain experience in the growing, tending, and maintenance of trees on agricultural land. It has been confirmed by both the research results (for instance, Reference [37]) and statistics showing that the total area of SRC (*Populus* spp., *Alnus incana*, and *Salix* spp.) on agricultural land in Latvia (supported by the Rural Support Service) increased from 607.5 ha in 2015 to 1042.5 ha in 2021 [66]. Nevertheless, the suitability of different tree species directly for agroforestry systems such as silvoarable systems, as well as potential interactions between woody plants and agricultural crops in northern and northeastern regions of Europe, has been little studied.

Agroforestry is a promising land-use practice with which to promote C biosequestration (the biologically mediated uptake and conversion of CO_2 into inert, long-lived, C-containing materials) and reduce GHG emissions from soil [14–16,26,67–70]. In general, the structures, components, farming activities, and management practices of agroforestry systems are very diverse; furthermore, agroforestry systems are structurally and functionally more complex than either croplands, grasslands, or tree monocultures [30,70].

This results in a large variation in estimates of sequestered C amount both in living and dead biomass, as well as in soil across a wide range of agroforestry systems [71]. However, to achieve the land-management target of sequestering C, the difference between C captured through photosynthesis and C returned to the atmosphere has to be positive [71,72]. Agroforestry systems generally fulfill this criterion; furthermore, the majority shows significantly higher C sequestration per area unit than in equivalent areas of land with crop/grass monocultures and similar or even higher levels of sequestration to that observed in forests [14,15,71,73]. An earlier study in Latvia [53] showed that agroforestry systems combining hybrid aspen (with distance between trees of 2.5 × 5.0 m) and perennial grasses or legumes sequestered up to 16.5 t CO_2 ha^{-1} in tree aboveground biomass during the first five years after establishment of an agroforestry system in mineral soil, corresponding to 0.9 t C ha^{-1} yr^{-1}. Celma et al. (2022) recently reported that, on marginal agricultural land in Latvia, hybrid aspen was more productive than birch and alder species, and even produced 4.8 t aboveground biomass ha^{-1} yr^{-1} (corresponding to 2.4 t C ha^{-1} yr^{-1}) during the first eight years after tree-seedling implementation in stony soil with a sandy loam texture, when the best clone and treatment combination was selected [58]. Lazdins et al. (2021) calculated that the establishment of birch plantations in cropland and grassland with mineral and organic soils in Latvia led to a reduction of GHG emissions by 7.9–44.4 tons of CO_2 eq. ha^{-1} yr^{-1} over a 40-year period; furthermore, in organic soils, GHG-emission reduction was significantly higher than in mineral soils [74]. Aertsens et al. (2013) assumed 2.75 t C ha^{-1} yr^{-1} to be the EU-27's technical potential for agroforestry on arable land and pastures [14]. More recently, Kay et al. (2019) reported that C-storage potential of the wood elements (including roots) of agroforestry systems in the European biogeographical region was between 0.09 and 7.29 t C ha^{-1} yr^{-1} [1]. EURAF (2020) reported estimates of total C sequestration potential in agroforestry systems in temperate regions varying between 1 and 12 t C ha^{-1} yr^{-1} depending on species, climate, soil, management, and rotation [15]. The C accumulation in soil is determined by the balance between inputs of organic matter and its subsequent rate of decomposition and loss, including leaching driven by relatively complex biogeochemical processes [14]. Although consensus does not always exist, most studies show that planting trees in agricultural (especially arable) environments leads to an increase in soil organic C stocks [71,75–78]. However, a limited number of field experiments have been specifically conducted to test the effects of agroforestry practices on soil organic C, and quantitative information about belowground C inputs in agroforestry systems is thus missing [68]. However, if it is assumed that average C sequestration in the selected agricultural land suitable for agroforestry in Latvia is 2.75 t C ha^{-1} yr^{-1}, and according to the Aertsens et al. (2013) [14], the total amount of potentially sequestered C is 966.6 kt C yr^{-1} or 3544.2 kt CO_2 yr^{-1} (including 843.2 kt C yr^{-1} in areas without underground drainage systems). It even exceeds total net GHG emissions from Latvian croplands and grasslands in 2020 (2889.7 kt CO_2 equivalent yr^{-1}) by 22.6% reported under the Land Use, Land-Use Change and Forestry (LULUCF) sector within Latvia's National GHG Inventory [41]. Thus, establishment of agroforestry systems could be a promising tool to reach GHG emission reduction targets for the LULUCF category.

The establishment and maintenance of new agroforestry systems can face several challenges. The results of focus-group discussions and surveys of farmers (landowners and land managers) across Europe indicated that excessive bureaucratization, high costs of establishment, uncertain profitability, lack of knowledge, practical demonstrations, recommendations for establishment and management, and lack of state support systems, as well as some skepticism and negative prejudices, are severe concerns among farmers [79–83]. Furthermore, in Latvia and other EU countries, the implementation of agroforestry systems on agricultural land is hindered by current legislation. Other hindering factors in Latvia include the lack of necessary knowledge (including demonstration sites) for landowners and land managers, lack of human resources in rural areas and suitable tractor machinery, lack of availability of tree planting material, potential risks of animal damage, and lack of availability of funding (and potential need for the redistribution of targeted subsidies). Legislation, strategies, or policies that can potentially reduce availability of area of agricultural lands suitable for agroforestry practice should also be mentioned—for instance, proposed EU legislation on rewetting drained farm peatlands aims to implement restoration measures on 30% of those peatlands of which at least a quarter must be rewetted by 2030, and to implement restoration measures on 70% of those peatlands of which at least half must be rewetted by 2050 [84]. We identified 31.1 kha of agricultural area with peat soils suitable for agroforestry in Latvia (Figure 6). These areas may be subject to restoration measures in the future. Another strategy that could potentially reduce the area of agricultural land available for agroforestry is the EU Biodiversity Strategy for 2030 called "Bringing nature back into our lives" [85], which sets the objective of establishing the Trans-European Nature Network to legally protect at least 30% of the land in the EU, including inland waters, of which at least one-third (10% of land) is to be under strict protection. Furthermore, part of the agricultural land with lower land-quality value that was identified as suitable for agroforestry within this study may become protected, and land-management activities may become limited or not allowed at all.

5. Conclusions

The proposed approach for the selection and evaluation of agricultural land suitable for agroforestry practices is applicable and provides detailed parcel-level (with identifiable location) information. The study covered Latvia as a demonstration area representing the hemiboreal region, but the provided approach is transferable to other countries and regions by adapting it to the locally available spatial data. The availability of high-resolution up-to-date LiDAR data is crucial for the adaptation of the methodology.

In summary, the total area of agricultural land parcels where agroforestry could provide a solution for more effective land management in Latvia was estimated to be 14.1% of the total agricultural land in Latvia (351.5 kha, including 306.6 kha of area without underground drainage systems). The largest part of the selected agricultural land suitable for agroforestry is based on semihydromorphic soils (mostly podzolic–gley and gley soils), and the dominant soil texture is loamy sand, followed by loam, sand, and peat. The soil type and texture in the selected agricultural land is suitable for introducing a wide range of tree species that would allow the establishment of agroforestry systems for various purposes. The current land use of the selected agricultural land comprises heterogeneous agricultural areas and pastures; however, the selected agricultural land is mostly outside intensive agricultural production: only 0.38% of the total selected agricultural land was declared under the Rural Support Service and approved to receive state and/or EU support to farmers under the CAP. Thus, establishment of agroforestry systems in less fertile agricultural land in accordance with the current land-use and management legislation could contribute significantly to achieving biodiversity and environmental and climate goals, while simultaneously ensuring multiple agricultural productions without reducing the area of high-value agricultural parcels.

Considering the lengthy process of implementation of new agricultural-land-management practices (including changes in legislation, support systems, preparation of recommendations, and education of landowners and land managers), as well as the ambitious timeframe for reaching biodiversity and environmental and climate goals, we recommend reducing hindrances to the introduction of agroforestry systems and relocating funding under the CAP to support measures, including agroforestry, that have the most significant GHG mitigation potential.

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Appendix A

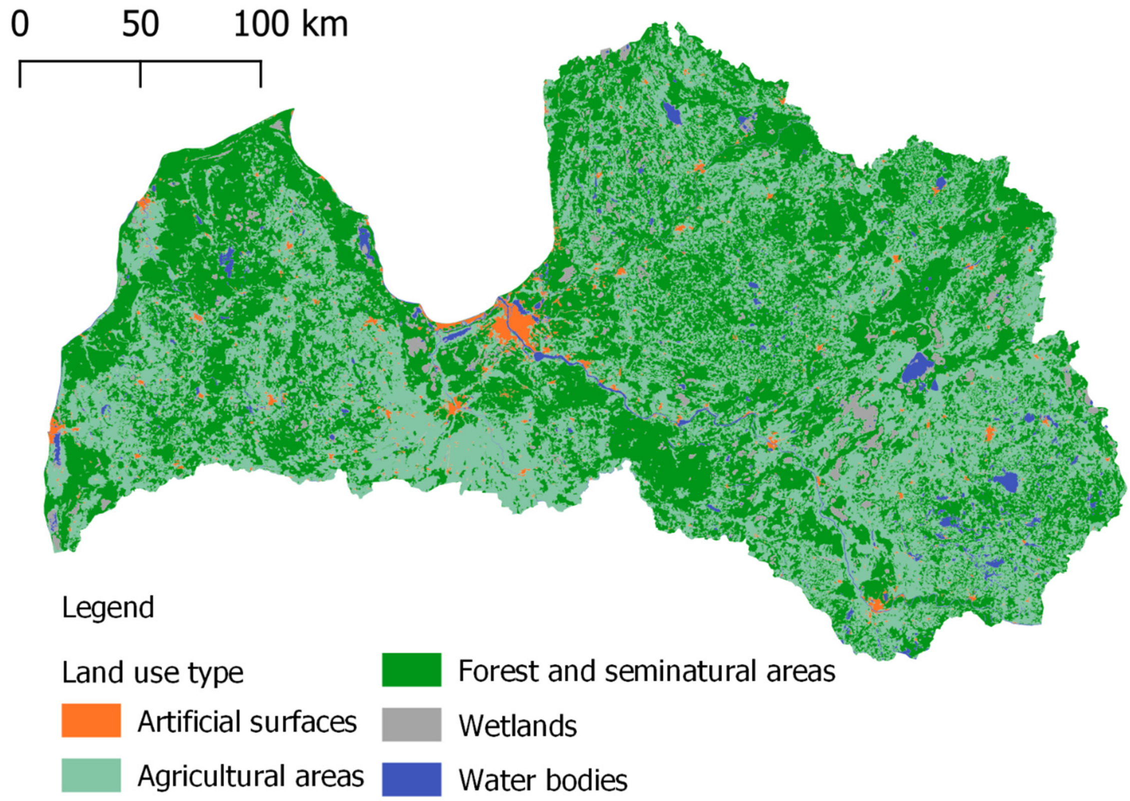

Figure A1. Land-use map of Latvia based on CORINE land-cover data.

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