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A Shortlisting Framework for Crop Diversification in the United Kingdom

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Abstract: We present a systematic framework for nationwide crop suitability assessment within the UK to improve the resilience in cropping systems and nutrition security of the UK population. An initial suitability analysis was performed using data from 1842 crops at 2862 grid locations within the UK, using climate (temperature and rainfall) and soil (pH, depth, and texture) data from the UK Met Office and British Geological Survey. In the second phase, additional qualitative and quantitative data are collected on 56 crops with the highest pedoclimatic suitability and coverage across the UK. An exercise was conducted on crops within each category using a systematic ranking methodology that shortlists crops with high value across a multitude of traits. Crops were ranked based on their nutritional value (macronutrients, vitamins, and minerals) and on adaptive (resistance to waterlogging/flood, frost, shade, pest, weed, and diseases and suitability in poor soils) and physiological traits (water-use efficiency and yield). Other characteristics such as the number of special uses, available germplasm through the number of institutions working on the crops, and production knowledge were considered in shortlisting. The shortlisted crops in each category are bulbous barley (cereal), colonial bentgrass (fodder), Russian wildrye (forage), sea buckthorn (fruit), blue lupin (legume), shoestring acacia (nut), ochrus vetch (vegetable), spear wattle (industrial), scallion (medicinal), and velvet bentgrass (ornamental/landscape). These crops were identified as suitable crops that can be adopted in the UK. We further discuss steps in mainstreaming these and other potential crops based on a systematic framework that takes into account local farming system issues, land suitability, and crop performance modelling at the field scale across the UK.

Keywords: climate change adaptation; underutilised crops; pedoclimate analysis; land evaluation; nutrition security

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1. Introduction

Diversification of production systems using currently neglected and underutilised crops is seen as a way to improve the productivity and resilience of cropping systems and ecosystem services [1–5]. Underutilised crops are crops that are locally adapted and consumed but are not currently part of mainstream agriculture. Diversified crop portfolios can improve climate resilience [6] and increase dietary diversity and human health by alleviating micronutrient deficiencies (lack of vitamins and minerals), which are associated with the quality of food that causes 'hidden hunger' in otherwise well-fed individuals [7–9].

Employing cropping systems that are focussed on a limited range of staple crops in benign climates may not be an effective strategy in a warming world, and there is a need to investigate the opportunities arising from a wider range of crops and production systems [10,11]. Khoshbakht and Hammer (2008) [12] estimated that about 35,000 cultivated plant species exist based on an initial list of 7000 cultivated species published by Rudolf Mansfeld in 1959. While the number of documented crops in agricultural databases is certainly less than this, mainstreaming the current list of underutilised crops into crop diversification projects remains a challenge. Underutilised crops have unrealised potential to improve local incomes, food and nutritional security, and resilience to climate change [11,13]. There is consensus that preserving the genetic resources of these species and their wild relatives is highly desirable. Nonetheless, there is much less emphasis on their inclusion into current and future farming portfolios and the development of supportive policies for their adoption at the local, regional, national, and global levels. A major challenge to utilising such crops is determining their suitability in local conditions, which usually requires many years of empirical research and data collection and large sums in investments [14].

Poor diets in Great Britain contribute to one in seven deaths, and the general burden of obesity has extended beyond 60% for both the male and female population since 2019 [15]. The dietary recommendation to eat a diverse diet containing plants links directly to the limited number of plants that are currently being cropped and consumed in a typical UK household diet [16].

The Agricultural Land Classification of England and Wales (ALC), which was first developed in the 1970s and 1980s and is still in use today, is based on a grading system that classifies land according to soil limitations to crop growth. A recent review of ALC in 2019 showed that these limitations and thresholds can be further refined in light of advances that are made in environmental data collection and analysis [17]. As a result, it is possible to develop highly relevant land capability analyses across the UK for major crops. For example, Bell et al. (2021) [18] developed land capability for 118 commercial crops in Wales based on current and future climate scenarios. The crop thresholds used in that study adopted rules that were further validated by experts who have extensive experience in working with specific crops. Such expert-based rules have proven to be beneficial for determining the suitability of crops that have a history in the country. However, the applicability of this methodology to crops that have not previously been grown in a country remains a challenge. Knight (2023) [19] has recently developed a list of 33 crops from six categories that were deemed important in the scientific literature and in collaboration with a panel of experts. This method is particularly useful to identify the current focus of research on local underutilised crops but can neglect novel crops with potential that were not the subject of research and investigation by the UK research community.

Several recent studies on underutilised crops have developed priority crop lists for different environments. Mabhaudhi et al. (2017) [20] established a priority list of crops based on scientific literature analysis and categorisation based on popularity and research themes to produce a list of species that responded to common issues in South Africa. Wimalasiri et al. (2022) [21] similarly developed priority lists for Italy, using a species niche classification method that was first proposed by Hijmans et al. (2001) [22] and utilised for suitability determination of agricultural species by Ramirez-Villegas et al. (2013) [23]. This was further refined to include soil information by Piikki et al. (2017) [24] and Jahanshiri et al. (2020) [25]. A suitability analysis of a large set of crops can be followed by a detailed analysis and ranking of crops based on available literature and documented evidence for highly suitable crops by recognised experts in the field.

Recent advances in data management and analytics have provided opportunities to store and organise data and identify research gaps for underutilised crops [26–28]. Stored data can be used to fill local and global gaps in knowledge on the suitability and performance of crops before committing resources to testing them [29,30]. Existing computational resources allow for rapid estimation of adaptability for a large number of crops [25], as well as detailed analyses of crop performance using minimum environmental information [31,32]. These analyses can potentially be used to derive estimates of returns on investments and economics for underutilised crops [33,34].

Here, we present an approach to developing a land-evaluation evidence base for a wide range of crops for the UK. Following a suitability analysis for many potential crops, priority lists were developed based on a shortlisting method that ranks crops based on germplasm availability and nutritional, physiological, and climate tolerance properties.

We further discuss the limitations of this approach and present a framework within which local crop diversification options can be evaluated locally.

2. Materials and Methods

An evidence base for underutilised crops was developed based on the suitability analysis for a large number of crops over a set of grid locations covering the whole of the UK. From this, crops with high suitability were chosen for further data collection and ranking using a rank summation index [21]. Figure 1 shows the flowchart of the analytical approach.

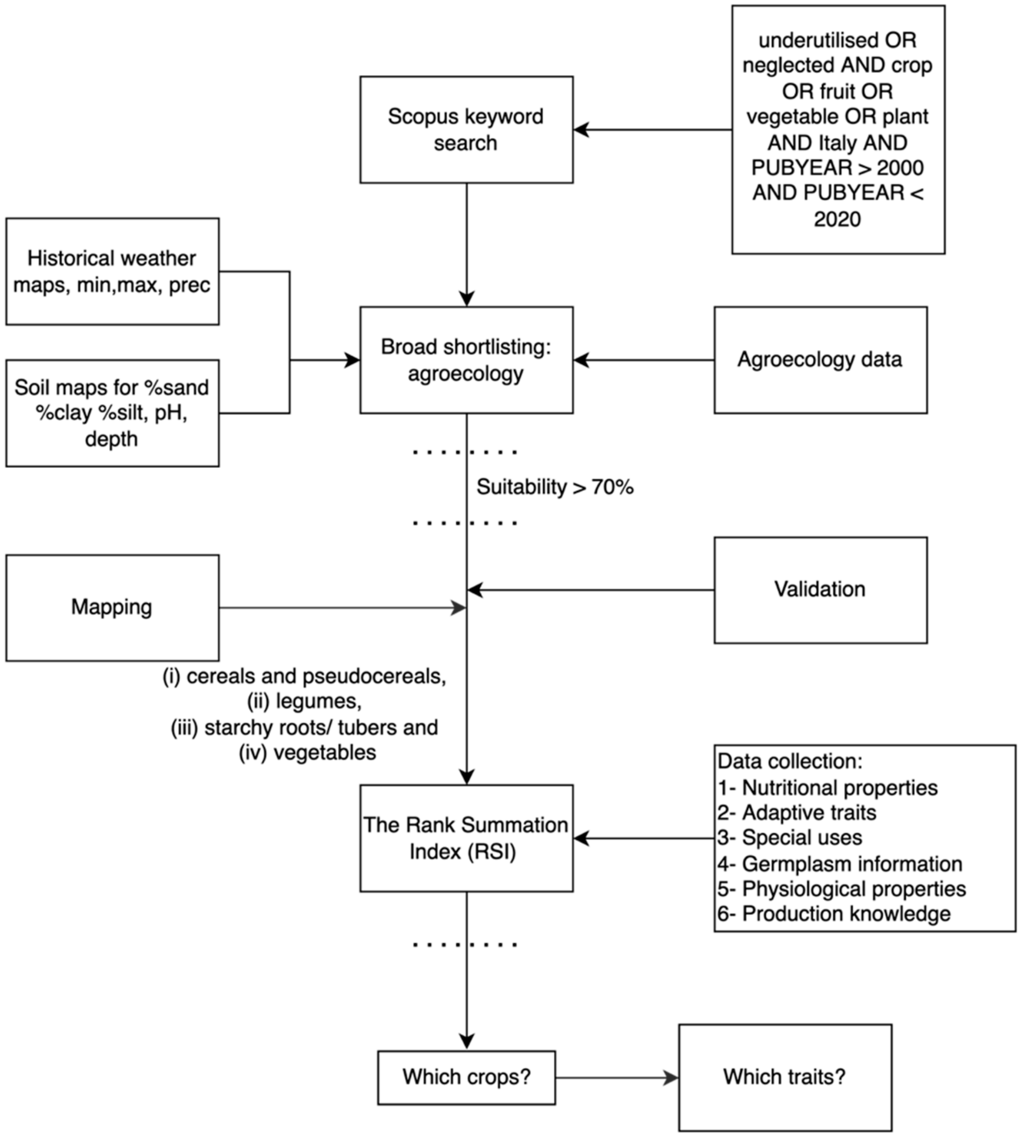

Figure 1. Flowchart of methodology and data.

2.1. Pedoclimatic Suitability Analysis

Crop shortlisting was carried out using data from a gridded long-term climate average dataset obtained from the UK Meteorological Office [35]. This dataset covers monthly averages for 30 years (1990–2020) at a resolution of 12 km. The 30-year period ensures it is the minimum period that is defined by the World Meteorological Organisation (WMO) to define 'climate' and to avoid natural climate cycles. Soil information in this analysis was obtained from the British Geological Survey (BGS) Soil Parent Material 1 km and soil chemistry datasets..

Ecological data for 1842 crops were extracted from the global knowledge base for underutilised crops [27]. This data contains optimal and marginal environmental requirements, including temperature, rainfall, soil acidity, fertility, texture, and depth. A grid of 2862 locations was created using geospatial functionalities in the R statistical language that allow vector geospatial analysis [36–38]. Soil and climate information were extracted for each grid point using raster analysis within the R language [39].

To adapt the algorithm that was originally developed by Jahanshiri et al. (2020) [25] to the UK data, some modifications were carried out. For example, because the BGS dataset contained pH data for only the topsoil, the algorithm was adjusted to derive pH suitability based on this layer alone. In addition, since the local rainfall data were available, the analysis of rainfall suitability was also performed in addition to the temperature suitability. The analysis was carried out for all grid points and the final maps were created using geo-visualisation capabilities within the R language [37,40]. Crop suitability at each grid point was determined by calculating the pedoclimate suitability for all 1842 crops on the scale of 0–100 (Highly unsuitable to highly suitable). As a result, a ranked array of suitability values for 1842 crops was created. To further refine the list at each grid point, only crops whose species niche suitability exceeded 70% and cover more that 1% of the country were selected. These crops were then plotted on a map to facilitate further refinement and validation.

The data used in this analysis were obtained from a variety of sources with different formats (Table 1). This makes quality control a necessary part of the analysis. Data representing the boundary of the UK from Global Administrative Areas (2012) [41] were examined to validate that they corresponded to the true boundaries. The ecology data from the Global Knowledge Base on underutilised crops [27] were checked and validated against the literature. A dataset of 25 randomly selected points was used, and the climate data from the Meteorological Office were extracted for those locations to check for any discrepancy with weather resources such as https://www.worldweatheronline.com/ (accessed on 23 November 2022). No checking for soil data was possible since there are no other comprehensive and freely available baseline geospatial data available for soil in the UK.

Table 1. List of data, formats, and sources.

Data	Type/Format	Source
Administrative areas	Geospatial/Shapefile	Global Administrative Areas (2012) [41]
Meteorological data	Geospatial/GeoTiff	UK Meteorological Office [35]
Soil data	Geospatial/Shapefile	British Geological Survey https://www.bgs.ac.uk (accessed on 1 October 2022))
Ecological data	Tabular/CSV	Global knowledge base for underutilised crops [27]
Wheat special occurrence	Tabular/M.S. Excel	Global Biodiversity Information Facility database [42]
Crop trait data	Tabular/reports, peer reviewed articles, etc.	Various sources (see https://doi.org/10.5281/zenodo.7670659 (accessed on 5 March 2023) for a complete list)

To aid the evaluation of outputs, a suitability map for wheat (*Triticum aestivum*) was produced using the same methodology. Wheat is a well-established and extensively grown crop in the UK. This suitability map was compared against known areas of wheat cultivation and production in the UK. To further validate these results, occurrence data from the Global Biodiversity Information Facility (GBIF) [42] were obtained and superimposed on the wheat suitability map to show the extent to which the suitability analysis performed in this study reflects the true distribution of this crop.

2.2. Rank Summation Index

Following a detailed literature analysis, indicator data related to selected underutilised crops were collected to carry out a quantitative analysis of the Rank Summation Index [21]. A multi-criteria rank index was developed based on the following information:

- Nutritional traits: proximate data for carbohydrate (g 100 g^{-1} dry matter), protein (g 100 g^{-1} dry matter), lipid (g 100g^{-1} dry matter), vitamin A (IU), vitamin B1 (Thiamine) (mg 100 g^{-1} dry matter), vitamin B2 (riboflavin) (mg 100 g^{-1} dry matter), vitamin B3 (niacin) (mg 100 g^{-1} dry matter), vitamin C (mg 100 g^{-1} dry matter), calcium (mg 100 g^{-1} dry matter), iron (mg 100 g^{-1} dry matter), and phosphorus (mg 100 g^{-1} dry matter).
- Adaptivity: the adaptive capacity of the crops for drought, waterlogging, frost, and shade tolerance. In addition, soil-related traits such as salinity and acid/alkaline tolerance were included. Other traits such as weed, pest, and disease tolerance were also collected (if they were available) to compare the resilience of the crops.
- Physiological traits: although physiological parameters pertaining to crop growth are extensive, efficiency in resource uptake and output yield are deemed most important in relation to crop adaptability to marginal environments. Water-use efficiency (WUE; g kg^{-1}) represents the dry matter that is produced per unit of water evaporated. WUE is particularly useful in comparing crops in limiting conditions [43].For this analysis, only data on WUE and potential yield were used for ranking. Crops with better mechanisms to adjust WUE to produce higher yield are deemed to have higher ability to physiologically adapt in marginal environments, increasing their utility.
- Other uses: most domesticated crops are multi-purpose, and ranking based on the number of uses is an option. Here the crops are ranked based on the number of uses other than their main purpose. Data from the literature were analysed to derive as many uses as possible for the selected crops including feed, medicinal, and industrial (additives, cosmetic, paper/textile/basketry, construction/plaiting, fuel, and biofuel).
- Germplasm: availability of crop genetic resources is vital for the wider adoption of any crop, and any diversification project involving new crops should start with identifying available accessions. In this regard, the number of global institutions working to preserve specimens or conduct research on a particular species, together with the number of accessions, are important.
- Production knowledge: collecting information about the production knowledge of crops, particularly those that are considered underutilised, is a difficult task and one that is usually neglected by academic disciplines. For this reason, information on the production knowledge was confined to only the approximate harvest time based on research that was already conducted on these crops. The production knowledge or approximate harvest time expressed as a shorter duration will be beneficial economically and in areas that are affected by climate change. This will render some crops suitable where growing seasons shrink.

Each of the above categories was then broken down into specific variables for data collection. For all data points, information related to source were also recorded as metadata. The ranking was applied for crops within each category. Information from the closest relatives of crops were used to fill the gaps in the available data on crops.

3. Results

Results are presented for two types of analysis related to underutilised crops in the UK, pedoclimatic suitability assessment results and a rank summation index for selected underutilised crops.

3.1. Pedoclimatic Shortlisting

From a list of 1842 crops at each grid point, five crops with >70% pedoclimatic suitability were chosen at the first round of selection. The list was further refined to include crops that are suitable for more than 1% of the UK area.

Table 2 shows a list of crops with average pedoclimatic suitability above 70% and area suitability > 1%. Since the suitability is highly variable across the country for all the crops, the data presented in Table 2 show the average suitability across the whole of the UK. Some crops are highly suitable for most of the country, while others are only suitable for a few locations. In total, there were 57 crops that met the criteria: forage (19), fodder (13), ornamental/landscape (8), environmental—soil improvement (11), medicinal (8), industrial (6), legumes (3), energy (3), fruits (3), fibre (3), cereals (2), vegetables—leafy/stem (2), starchy—roots/tubers (1), beverage (2), essential oil (1), oilseed (1), grain (1), and others (15). However, many crops are also used for purposes other than their main purpose.

To assess the validity of the outputs, a suitability map for wheatwas compared with known wheat-growing areas [44] and production (area x yield) across the UK [45]. Due to lack of detail soil data, the area of Northern Ireland was not included in the analysis. Ground location of 66,188 species occurrence for wheat from the GBIF database [42] was also superimposed on the suitability map (Figure 2). Although the methodology classify most of the grid locations as moderately suitable (45%) and suitable (16%), some misclassification is present on the map. This is particularly apparent for Wales, where the suitability should be low (see Appendix A, Figure A2).

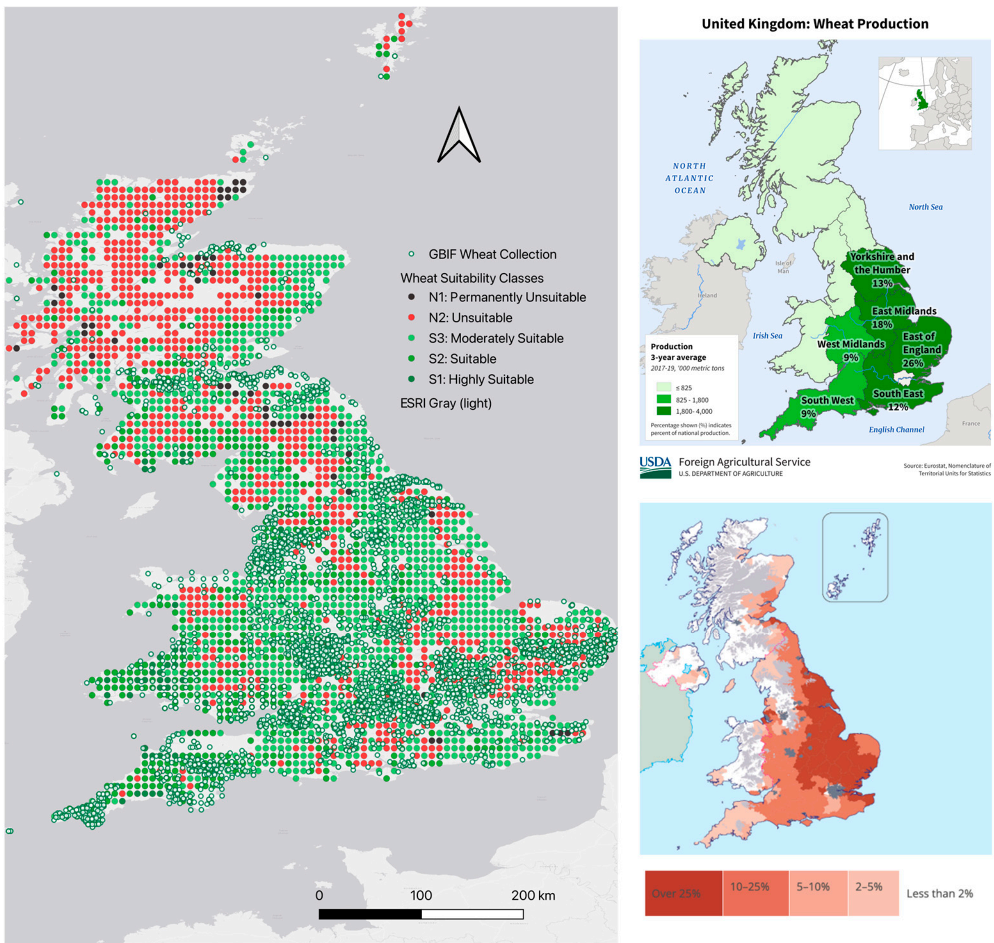

Figure 2. Suitability map of wheat within the UK based on the present methodology (left) against a map of areas under cultivation (bottom right) and a yield map of wheat (top right) for the UK.

Table 2. Highly suitable crops for the UK (suitability > 70% and coverage > 1%).

Name	Scientific Name	Mean	Cover	Family	Types							
Colonial Bentgrass	*Agrostis tenuis*	88.8	39.7	Poaceae	Fodder	Ornamental/ landscape	Turf					
Velvet Bentgrass	*Agrostis canina*	85.7	33.0	Poaceae	Ornamental/ landscape							
Bramble Wattle	*Acacia victoriae*	93.2	32.0	Leguminosae	Legumes	Medicinal	Industrial	Energy				
European Larch	*Larix decidua*	90.1	31.4	Pinaceae	-							
Tall Wheatgrass	*Agropyron elongatum*	93.5	27.6	Poaceae	Forage	Fodder	Environmental	Energy	Industrial			
Brown Bentgrass	*Agrostis trinii*	88.5	27.1	Poaceae	Fodder							
Rough Grass	*Cleistogenes squarrosa*	91.4	25.7	Poaceae	Forage							
Sandplain Wattle	*Acacia murrayana*	91.2	24.6	Leguminosae	-							
Quail Bush	*Atriplex lentiformis*	95.2	19.7	Amaranthaceae	Forage							
Frost Grass	*Spodiopogon sibiricus*	85.1	19.7	Poaceae	Ornamental/ landscape							
Sea Buckthorn	*Hippophae rhamnoides*	93.9	18.6	Elaeagnaceae	Fruits	Beverage	Medicinal	Industrial				
Acacia	*Acacia pachyacra*	93.2	17.7	Leguminosae	-							
Mongolian Wheatgrass	*Agropyron mongolicum*	90.3	9.0	Poaceae	Forage							
European Beech	*Fagus sylvatica subsp. sylvatica*	92.9	8.9	Fagaceae	Fodder	Forage	Ornamental/ landscape	Environmental	Industrial	Medicinal		
Oldman Saltbush	*Atriplex nummularia*	92.8	7.6	Amaranthaceae	Forage	Ornamental/ landscape						
Triticale	*Secale cereale x Triticum aestivum*	90.5	7.1	Poaceae	Cereals	Fodder	Industrial					
Gardner Saltbush	*Atriplex gardneri*	97.5	6.2	Amaranthaceae	Forage							
Bulbous Barley	*Hordeum bulbosum*	95.1	5.0	Poaceae	Cereals							
Reed Mace	*Typha latifolia*	83.7	4.9	Typhaceae	Forage	Fodder	Starchy	roots/tubers	Environmental	Energy	Ornamental/ landscape	Medicinal
Water Foxtail	*Alopecurus geniculatus*	87.1	4.6	Poaceae		grain						
Arundinella Grass	*Arundinella hirta*	83.7	4.5	Poaceae	Forage							
White Fir	*Abies concolor*	82.6	4.5	Pinaceae	Medicinal							
Blue Lupine	*Lupinus angustifolius*	91.3	4.3	Leguminosae	Legumes	Environmental	(nitrogen	fixer)				
Shoestring Acacia	*Acacia stenophylla*	87.3	4.3	Leguminosae	-							
Coonavittra Wattle	*Acacia jennerae*	91.5	4.2	Leguminosae	-							

Table 2. *Cont.*

Name	Scientific Name	Mean	Cover	Family	Types				
Needle Grass	*Stipa caucasica*	95.8	4.0	Poaceae	Fodder				
Bladder-pod	*Lesquerella fendleri*	95.9	3.9	Brassicaceae	Oilseed				
Bushgrass	*Calamagrostis epigejos*	83.4	3.9	Poaceae	Ornamental/ landscape	Environmental			
Low-bush Blueberry	*Vaccinium angustifolium*	83.3	3.8	Ericaceae	Fruits	Beverage			
White Pea	*Lathyrus sativus*	96.9	3.6	Leguminosae	Legumes				
Bulbous Bluegrass	*Poa bulbosa*	92.8	3.1	Poaceae	Forage	Environmental			
Ochrus Vetch	*Lathyrus ochrus*	94.0	3.0	Leguminosae	-				
Russian Brome Grass	*Bromus tomentellus*	93.7	2.9	Poaceae	Forage	Environmental			
Bluebunch Wheatgrass	*Agropyron spicatum*	92.7	2.6	Poaceae	Forage				
Wolf Needle Grass	*Stipa baicalensis*	87.4	2.6	Poaceae	Forage	Fodder			
American Beech	*Fagus grandifolia*	79.9	2.6	Fagaceae		Industrial			
Tamarugo	*Prosopis tamarugo*	89.8	2.5	Leguminosae	-				
Fourwing Saltbush	*Atriplex canescens*	90.9	2.4	Amaranthaceae	Fodder	Ornamental/ landscape	Vegetables	(leafy/stem)	
Small Reed Mace	*Typha angustifolia*	85.0	2.3	Typhaceae	Fodder	Starchy	roots/tubers	Fibre	Environmental
Sulla Epineux	*Hedysarum spinosissimum*	96.4	2.2	Leguminosae	-				
Gobi Needle Grass	*Stipa tianschanica*	96.4	2.0	Poaceae	Forage				
Sea Buckthorn	*Hippophae salicifolia*	98.7	1.8	Elaeagnaceae	Fruits	Medicinal	Essential	oil	
Chewing's Fescue	*Festuca rubra var. commutata*	96.7	1.6	Poaceae	Fibre				
Quackgrass	*Agropyron repens*	93.7	1.6	Poaceae	Medicinal				
Scallion	*Allium cepa*	97.9	1.5	Amaryllidaceae	Medicinal	Vegetables	(leafy/stem)	Vegetables	(root/bulb/tuber)
Sulla Rose	*Hedysarum carnosum*	96.1	1.4	Leguminosae	-				
Spear Wattle	*Acacia jensenii*	90.8	1.4	Leguminosae	-				
Dwarf Feather Grass	*Stipa capillata*	86.9	1.4	Poaceae	-				
Shadscale	*Atriplex confertifolia*	83.2	1.4	Amaranthaceae	Forage				
Dune Wattle	*Acacia ligulata*	85.2	1.3	Leguminosae	-				
Onions 'var. cepa'	*Allium cepa var. cepa*	99.9	1.2	Amaryllidaceae	Vegetables	(root/bulb/tuber)			
Quandong	*Santalum acuminatum*	90.7	1.2	Santalaceae	-				
Gidgee	*Acacia cambagei*	88.6	1.2	Leguminosae	-				

Table 2. *Cont.*

Name	Scientific Name	Mean	Cover	Family	Types		
Standard Crested Wheatgrass	*Agropyron desertorum*	86.0	1.2	Poaceae	Fodder		
Western Wheatgrass	*Agropyron smithii*	85.2	1.2	Poaceae	Forage	Fodder	Environmental
Idaho Fescue	*Festuca idahoensis*	96.9	1.1	Poaceae	Forage		
Russian Wildrye	*Psathyrostachys juncea*	94.0	1.1	Poaceae	Forage	Fodder	Environmental
Chee Grass	*Achnatherum splendens*	91.3	1.0	Poaceae	Forage	Fibre	Environmental
Coolibah	*Eucalyptus microtheca*	76.7	1.0	Myrtaceae	-		

3.2. Multi-Criteria Ranking

Of the 57 crops shown by pedoclimatic analysis to be potentially suited to the UK, only those that had complete data present in the dataset were selected for further ranking. For each category of crop (cereals, legumes, forage, etc.), the crop with the highest desirable characteristics was scored with the lowest number. For example, the lowest score was given to the crop with the highest nutritional quality. A final ranking was produced by summing all scores (unweighted) for all criteria for all crops. Crops with the lowest scores (highest rank and adaptability) were identified as the crops with the greatest potential across the UK.

3.2.1. Nutritional Traits

Since the rank summation index methodology does not accept missing information, only 22 crops were selected for further analysis of ranking (Table 3 and Appendix A, Table A1 for nutrition data). Bulbous barley (*Hordeum bulbosum*), dune wattle (*Acacia ligulata*), Russian wildrye (*Psathyrostachys juncea*), sea buckthorn (*Hippophae rhamnoides*), blue lupin (*Lupinus angustifolius*), shoestring acacia (*Acacia stenophylla*), ochrus vetch (*Lathyrus ochrus*), scallion (*Allii fistulosi*), spear wattle (*Acacia jensenii*), and velvet bentgrass (*Agrostis canina*) were chosen as candidate crops.

3.2.2. Adaptive Traits

Table 4 shows the adaptability analysis for the shortlisted crops. Crops that show high resilience in this category are triticale, colonial bentgrass, Russian wildrye, sea buckthorn, bramble wattle, shoestring acacia, ochrus vetch, spear wattle, and velvet bentgrass, and they were chosen as candidate crops.

3.2.3. Physiological Traits

Table 5 shows the rank summation indices for select physiological traits. Triticale and bulbous barley, colonial bentgrass, Russian wildrye, sea buckthorn, quandong, white pea, onion, velvet bentgrass, scallion, spear wattle, and ochrus vetch ranked high based on the select physiological characteristics.

3.2.4. Other Uses

Table 6 shows the data and the rank summation methodology for other uses. Bulbous barley, dune wattle, reed mace, both sea buckthorn and quandong, both bramble wattle and blue lupin, both sandplain plain wattle and shoestring acacia, velvet bentgrass, scallion and spear wattle, and ochrus vetch were chosen as candidate crops.

3.2.5. Germplasm

After ranking crops based on the number of institutions working on them, bulbous barley, colonial bentgrass, brown bentgrass, reed mace, tall wheatgrass, sea buckthorn, white pea, and ochrus vetch ranked high based on their physiological characteristics (Table 7). No global institution is working on the nuts group, and therefore, all the crops in this category are given the same rank, while velvet bentgrass, scallion, spear wattle, and ochrus vetch are automatically chosen as candidate crops.

3.2.6. Production Knowledge

Table 8 shows the ranking within categories based on harvest time. Triticale, colonial bentgrass, tall wheatgrass, quandong, blue lupin, coonavittra wattle, ochrus vetch, velvet bentgrass, scallion, and spear wattle were chosen as candidate crops with the shortest time to harvest.

Table 3. Ranks of nutritional traits for crops that are suitable for the UK.

	Crop	Macro Rank	Vitamin Rank	Mineral Rank	Sum of Ranks	Final Rank
Cereals	Triticale (*Secale cereale xTriticum aestivum*)	2	2	1	5	2
	Bulbous Barley (*Hordeum bulbosum*)	1	1	2	4	1
Fodder	Colonial Bentgrass (*Agrostis tenuis*)	1	2	1	4	2
	Brown Bentgrass (*Agrostis trinii*)	1	2	1	4	2
	Dune Wattle (*Acacia ligulate*)	1	1	1	3	1
Forage	Tall Wheatgrass (*Agropyron elongatum*)	4	4	1	9	4
	Reed Mace (*Typha latifolia*)	3	2	2	7	2
	Sulla Rose (*Hedysarum carnosum*)	2	1	4	7	2
	Russian Wildrye (*Psathyrostachys juncea*)	1	3	2	6	1
Fruits	Sea Buckthorn (*Hippophae rhamnoides*)	1	1	1	3	1
	Quandong (*Santalum acuminatum*)	2	2	2	6	2
Industrial	Spear Wattle (*Acacia jensenii*)	2	1	1	4	
Legumes	Bramble Wattle (*Acacia victoriae*)	2	3	1	6	2
	Blue Lupine (*Lupinus angustifolius*)	1	2	1	4	1
	White Pea (*Lathyrus sativus*)	3	1	3	7	3
Medicinal	Scallion (*Allii fistulosi*)	1	1	1	3	
Nuts	Sandplain Wattle (*Acacia murrayana*)	1	2	3	6	3
	Shoestring Acacia (*Acacia stenophylla*)	1	1	1	3	1
	Coonavittra Wattle (*Acacia jennerae*)	1	1	1	3	1
Ornamental/landscape	Velvet Bentgrass (*Agrostis canina*)	1	0	1	2	
Vegetables	Onions (*Allium cepa*)	2	2	1	1	2
	Ochrus Vetch (*Lathyrus ochrus*)	1	1	1	2	1

Table 4. Ranking of adaptive traits of crops suitable for the UK.

	Crop	Resistance/Tolerance Traits										
		Drought	**Water-logging**	**Frost**	**Shade**	**Salinity**	**Acidic/ Alkaline Soil**	**Infertile Poor Soil**	**Weed**	**Pest and Disease**	**SR ***	**Rank**
Cereals	Triticale	√	√			√	√ (Alkaline)			√	5	1
	Bulbous Barley										0	2
Fodder	Colonial Bentgrass	√					√ (Acidic)	√			3	1
	Brown Bentgrass	√									1	3
	Dune Wattle	√				√					2	2
Forage	Tall Wheatgrass	√				√	√ (Alkaline)				3	2
	Reed Mace		√				√ (Both low and high)				2	4
	Sulla Rose	√				√	√ (alkaline)				3	2
	Russian Wildrye	√		√		√	√ (Alkali)				4	1
Fruits	Sea Buckthorn	√				√	√ (Both)	√			4	1
	Quandong	√									1	2
Industrial	Spear Wattle	√									1	
Legumes	Bramble Wattle	√		√	√	√	√ (Alkaline)	√			6	1
	Blue Lupine	√	√				√ (Acid)				3	2
	White Pea	√				√					2	3
Medicinal	Scallion	√										
Nuts	Sandplain Wattle	√					√ (Both)	√			3	2
	Shoestring Acacia	√	√			√	√ (Alkaline)		√		5	1
	Coonavittra Wattle	√					√				2	3
Ornamental/landscape	Velvet Bentgrass	√		√	√		√ (Acidic)	√			5	
Vegetables	Onions 'var. cepa'	√									1	2
	Ochrus Vetch	√					√ (Mild acid and mild alkaline)				2	1

* SR: sum of ranks.

Table 5. Ranking based on physiological characteristics of crops suitable for the UK.

	Crop	Water Use Efficiency (kg ha^{-1}mm^{-1})	WUE Rank	Potential Yield (kg ha^{-1})	Yield Rank	Rank Sum	Final Rank
Cereals	Triticale	13.9	2	10,000	1	3	1
	Bulbous Barley	17	1	5930.6	2	3	1
Fodder	Colonial Bentgrass	18	1	1710	1	2	1
	Brown Bentgrass	18	1	120	3	4	2
	Dune Wattle	3.76	3	1027	2	5	3
Forage	Tall Wheatgrass	5.092	1	5610	4	5	2
	Reed Mace	-	3	7000–10,000	2	5	2
	Sulla Rose	-	3	8900	3	6	4
	Russian Wildrye	3.76	2	589,000	1	3	1
Fruits	Sea Buckthorn	12	1	5000	2	3	1
	Quandong	-	2	25,000	1	3	1
Grain							
Industrial	Spear Wattle	3.76	1	1027	1	2	
Legumes	Bramble Wattle	3.76	1	1250	3	4	2
	Blue Lupin	-	3	2000	2	5	3
	White Pea	4.2	2	5660	1	3	1
Medicinal	Scallion	20.54	1	19,790	1	2	
Nuts	Sandplain Wattle	3.76	1	1250	1	2	1
	Shoestring Acacia	3.76	1	1250	1	2	1
	Coonavittra Wattle	3.76	1	1027	3	4	3
Ornamental/landscape	Velvet Bentgrass	18	1	1710	1	2	
Vegetables	Onions 'var. cepa'	169	1	8800	1	2	1
	Ochrus Vetch	-	2	2440	1	4	2

Table 6. Ranking based on number of uses of crops suitable for the UK.

	Crop	Animal Feed	Medicinal	Industrial Processed Products					Score	Rank
				Food Additives	Cosmetic/Detergent	Paper/Textile/Basketery	Construction/Plaiting	Fuel/Biofuel		
Cereals	Triticale	√	√	√				√	4	2
	Bulbous Barley	√	√	√		√			5	1
Fodder	Colonial Bentgrass	√							1	2
	Brown Bentgrass	√							1	2
	Dune Wattle		√	√			√	√	4	1
Forage	Tall Wheatgrass	√						√	2	3
	Reed Mace		√	√		√		√	4	1
	Sulla Rose	√	√	√					3	2
	Russian Wildrye	√							1	4
Fruits	Sea Buckthorn	√	√	√	√				4	1
	Quandong		√	√			√	√	4	1
Industrial	Spear Wattle						√	√	2	
Legumes	Bramble Wattle		√	√			√	√	4	1
	Blue Lupine	√	√	√	√				4	1
	White Pea	√	√	√					3	3
Medicinal	Scallion		√	√					2	
Nuts	Sandplain Wattle	√	√	√			√	√	5	1
	Shoestring Acacia	√	√	√			√	√	5	1
	Coonavittra Wattle	√	√	√				√	4	3
Ornamental/landscape	Velvet Bentgrass	√							1	
Vegetables	Onions 'var. cepa'		√	√					2	2
	Ochrus Vetch	√	√	√					3	1

Table 7. Ranking based on the number of global institutions working on preserving accessions of specific crops.

	Name	Number of Institutions	Rank
Cereals	Triticale	1	2
	Bulbous Barley	2	1
Fodder	Colonial Bentgrass	4	1
	Brown Bentgrass	4	1
	Dune Wattle	0	3
Forage	Tall Wheatgrass	2	1
	Reed Mace	0	3
	Sulla Rose	0	3
	Russian Wildrye	2	1
Fruits	Sea Buckthorn	3	1
	Quandong	2	2
Industrial	Spear Wattle	0	
Legumes	Bramble Wattle	0	2
	Blue Lupine	0	2
	White Pea	13	1
Medicinal	Scallion	2	
Nuts	Sandplain Wattle	0	1
	Shoestring Acacia	0	1
	Coonavittra Wattle	0	1
Ornamental/landscape	Velvet Bentgrass	5	
Vegetables	Onions 'var. cepa'	2	2
	Ochrus Vetch	12	1

Table 8. Ranking based on the number of institutions working on specific crops.

	Name	Approximate Harvest Time (Day after Planting)	Rank
Cereals	Triticale	115	1
	Bulbous Barley	169	2
Fodder	Colonial Bentgrass	40	1
	Brown Bentgrass	55	2
	Dune Wattle	1826	3
Forage	Tall Wheatgrass	10	1
	Reed Mace	40	2
	Sulla Rose	100	3
	Russian Wildrye	730	4
Fruits	Sea Buckthorn	120	2
	Quandong	10	1
Industrial	Spear Wattle	1826	
Legumes	Bramble Wattle	2922	3
	Blue Lupine	30	1
	White Pea	100	2
Medicinal	Scallion	84	
Nuts	Sandplain Wattle	2922	2
	Shoestring Acacia	2922	2
	Coonavittra Wattle	2191	1
Ornamental/landscape	Velvet Bentgrass	40	
Vegetables	Onions 'var. cepa'	182	2
	Ochrus Vetch	152	1

3.2.7. Final Rank

The final multicriterial rank was assigned based on the sum of all rank summation indices for each category (Table 9). The lower the score, the better its rank will be in terms of all chosen factors. Bulbous barley, colonial bentgrass, Russian wildrye, sea buckthorn, blue lupin, shoestring acacia, ochrus vetch, spear wattle, scallion, and velvet bentgrass are crops with highest ranks (i.e., most suitable) for each category.

Table 9. Final rank of ranks of suitable crops for the UK.

	Name	Nutrition	Adaptive Traits	Special Uses	Physiology	Germplasm	Production Knowledge	Score	Rank
Cereals	Triticale	2	1	2	1	2	1	9	2
	Bulbous Barley	1	2	1	1	1	2	8	1
Fodder	Colonial Bentgrass	2	1	2	1	1	1	8	1
	Brown Bentgrass	2	3	2	2	1	2	12	2
	Dune Wattle	1	2	1	3	3	3	13	3
Forage	Tall Wheatgrass	4	2	3	2	1	1	13	2
	Reed Mace	2	4	1	2	3	2	14	3
	Sulla Rose	2	2	2	4	3	3	16	4
	Russian Wildrye	1	1	4	1	1	4	12	1
Fruits	Sea Buckthorn	1	1	1	1	1	2	7	1
	Quandong	2	2	1	1	2	1	9	2
Industrial	Spear Wattle	1	1	1	1	1	1	6	
Legumes	Bramble Wattle	2	1	1	2	2	3	11	2
	Blue Lupine	1	2	1	3	2	1	10	1
	White Pea	3	3	3	1	1	2	13	3
Medicinal	Scallion	1	1	4	1	1	1	9	
Nuts	Sandplain Wattle	3	2	1	1	0	2	9	2
	Shoestring Acacia	1	1	1	1	0	2	6	1
	Coonavittra Wattle	1	3	3	3	0	1	11	3
Ornamental/landscape	Velvet Bentgrass	1	1	1	1	1	1	6	
Vegetables	Onions 'var. cepa'	2	2	2	1	2	2	11	2
	Ochrus Vetch	1	1	1	2	1	1	7	1

4. Discussion

4.1. Crop Pedoclimate Matching

Traditional land evaluation frameworks are not suited to evaluate options for a large number of crops either grown as monocultures or in mixed systems. Inclusion of crops that are currently neglected and underutilised will improve the resiliency of such land evaluation frameworks by expanding the cropping options. However, local land evaluation studies are often limited by the availability of (1) local climate and soil data, (2) local experimental data, and (3) crop physiological data. The availability of datasets therefore determines the type of analysis that can be done to evaluate crop portfolios at any location, and the poor availability of data for crops that are neglected and underutilised hinders their wider use in developing crop portfolios. Methodologies that can use limited crop and environmental parameters may perform better in such circumstances. Current advances in development and storage of data allow for a more locally relevant analysis to be conducted at any location [46]. However, data such as socio-economic information remain scarce [47].

The methodology that was developed by Hijmans et al. (2001) [22] and further refined by Piikki et.al. (2017) [24] and Jahanshiri et al. (2020) [25] can be utilised to develop numerical suitability for a large number of crops. This paradigm shift allows for inclusion of more crops in the local analysis of land suitability [25,48]. A major drawback of this method, however, is to choose a priority list of crops from a longer list (1842 crops in this case). The arbitrary selection rules of average suitability > 70% and coverage area > 1% could therefore be expanded or refined to include other criteria or boundaries (e.g., greater suitability or coverage area) that can be selected by the end user or policy maker. The result of pedoclimatic analysis (Section 3.2) shows that there is ample potential for crops to be adapted to the UK's humid temperate, oceanic climate with tundra and subarctic conditions, particularly in northern areas [49]. Therefore, crops that are resilient to marginal environments may become increasingly suitable to UK conditions both now and in future climates. However, irrespective of changes in climate, limitations in soil, including acidity and texture, will limit the number of suitable crops (see Appendix A, Figure A2).

There is ample evidence of the positive impacts of crop diversification. For example, using portfolio risk management, Paut et al. (2019) [50] showed that an appropriate combination of suitable crops can reduce the financial risk in production systems up to 77%. Crop diversification can also improve the biodiversity in a win–win situation against yield, where improving diversity in the farming system (inter-cropping and use of cover crops) is combined with sustainable practices such as reducing agrochemical use, particularly in temperate climates [2]. Therefore, any recommendation for crop diversification would not be complete without analysing the most suitable combination of crops and cropping systems. A successful crop diversification strategy should be able to recommend inter-cropping or mixed-cropping systems as well [51]. A consequence of producing a broad list of adaptable crops is the ability to recommend systems for different categories of crops such as perennial/annual (for optimal production), legume/cereal (for soil fertility), and ornamental/industrial (landscape projects) and at different scales to enable farmers to influence the trade-offs between resilience and economic benefits [4]. Further investigation of productivity in diversified systems is possible through crop performance modelling [31].

The validation case for wheat as a major crop in the UK shows that the methodology can correctly identify areas with potential for wheat. However, there were two major issues: (1) the classification system identifies most areas as 'moderate to highly suitable' and (2) the best season for crop cultivation is considered as summer to autumn (see Appendix A, Figure A1). Both abovementioned issues combined with the current limitation of climate data from the Meteorological Office [35] and soil data from BGS [52] could lead to misclassification of suitable land. On one hand, the south-eastern part of the country should clearly be defined as highly suitable (Figure 2), and on the other hand, it is clear that most of the modern wheat varieties that are cultivated in the country are sown in the autumn rather than the spring [53]. Appendix A, Figure A1 shows the improvements that have been made on wheatto become highly adapted to the UK climate. Therefore, it is important to consider that because of the simplicity of the parameters and methods, this methodology is limited in detail. However, it is still useful in shortlisting crops a priori with potential from a much wider list of crops.

4.2. Trait Ranking

A systematic ranking based on common crop traits that are important for developing a priority list of crops can be used to further refine the crop list. A limitation of this method is that data needs to be available for all crops across all traits to allow for quantitative comparisons. This will lead to exclusion of many crops from the list (Tables 2–9 and Appendix A, Table A2). To fill the gaps in data as much as possible, our literature search was extended to the relatives of each species. Since the focus of this study is mainly on improving food and nutritional security, the crop list was amended to include crops that have complete nutrition datasets. However, this criterion does not apply to industrial, medicinal, and ornamental crops. Other traits such as area under cultivation and trade statistics were omitted in this study because of the lack of data for most crops. The data that were collected from the literature were also checked randomly to ensure quality. A limitation of systematic data collection is uncertainty in categorisation. A good example is the ochrus or Cyprus vetch crop [54,55]. Not only is there confusion about the scientific name of this crop, but there is also ambiguity as to which category the crop belongs to. However, using categories will improve the usability of crops in the main diversification plans.

The shortlisted crops are only a sample of species that have the potential to future-proof the UK's agriculture. Bulbous barley is a perennial hardy crop that is being domesticated for the subarctic climates [56]. Perennial cereal crops can reduce the environmental impact of agriculture whilst improving the resiliency of crops against climate change. The introduction of resilient fodder, forage, or ornamental crops such as colonial bentgrass, Russian wildrye, and velvet bentgrass with proven performance in low-input systems [57–59] could revive the marginal areas within the UK. Both crops ranked high in key traits that lead to their selection as final crops.

Sea buckthorn is a hardy tree with many benefits that can be grown in milder climates within the UK and create financial opportunities for growers [60]. Blue lupin contains low amounts of starch (gluten free) and high fibre content that can provide many health benefits [61]. It particularly ranked high in terms of nutrition and number of other uses, indicating its potential to be used as a multi-purpose crop. The acacia family of tree crops can be grown as drought- and salt-tolerant crops [62] that can also find applications as food and feed [63].

Ochrus vetch is a high-potential crop, particularly in the Mediterranean region, that is used as nutrition food. This crop can particularly help diversify and reduce the dependence of vegetable imports in the temperate regions of the UK [64]. Although wattles are considered invasive in some areas (for example, Australia), they are cultivated for wood because of their fast-growing properties. They are also highly regarded for their role in providing ecosystem services [65]. Although scallion (or spring onion) is not considered a medicinal crop in the UK, there is ample evidence for it to be considered for its anti-fungal/bacterial [66] and anti-cancer properties, as well [67].

4.3. A Pathway to Transformation

The increased attention in the UK research community to underutilised crops has resulted in the recognition of crop diversification as a viable option to tackle threatening issues facing UK farming systems [68,69]. However, results also show that any interest remains at the level of recommendation and advice rather than at developing specific pathways and road maps to diversify UK agriculture or routes to market for underutilised cops. This has an important consequence for the future of crop diversification in the UK, as the adoption of crops is still considered to be risky and remains at the level of trial and error, as the recent example of quinoa shows [70].

The proposed framework for crop diversification introduced in this paper can be expanded to include estimations of likely yield and economic impact after broad selection and trait ranking. Figure 3 shows the decision tree that can be used to further refine the list of crops based on pedoclimatic suitability and trait ranking. A farming system survey can be used to refine the list of locally relevant traits. After this stage, if minimum field data at cultivar and species level are available, simple crop models such as the one described by Zhao et al. (2019) [32], or modified ones [31] can be developed with data from the literature analysis to determine the likely yield for crop that pass the initial suitability analysis. On the other hand, if minimum field data are not available, an analysis can be performed for a wide range of varieties and accessions with known origins to shortlist possible germplasm that might perform well at any location. Such cases can be upscaled across regions and countries for a large number of potential underutilised crops such as in the study that was presented for hemp in Malaysia [34]. The UK's robust crop innovation, seed system, and variety development capacities can facilitate mainstreaming locally neglected crops, while other crops can face regulatory issues before they can be utilised within the country.

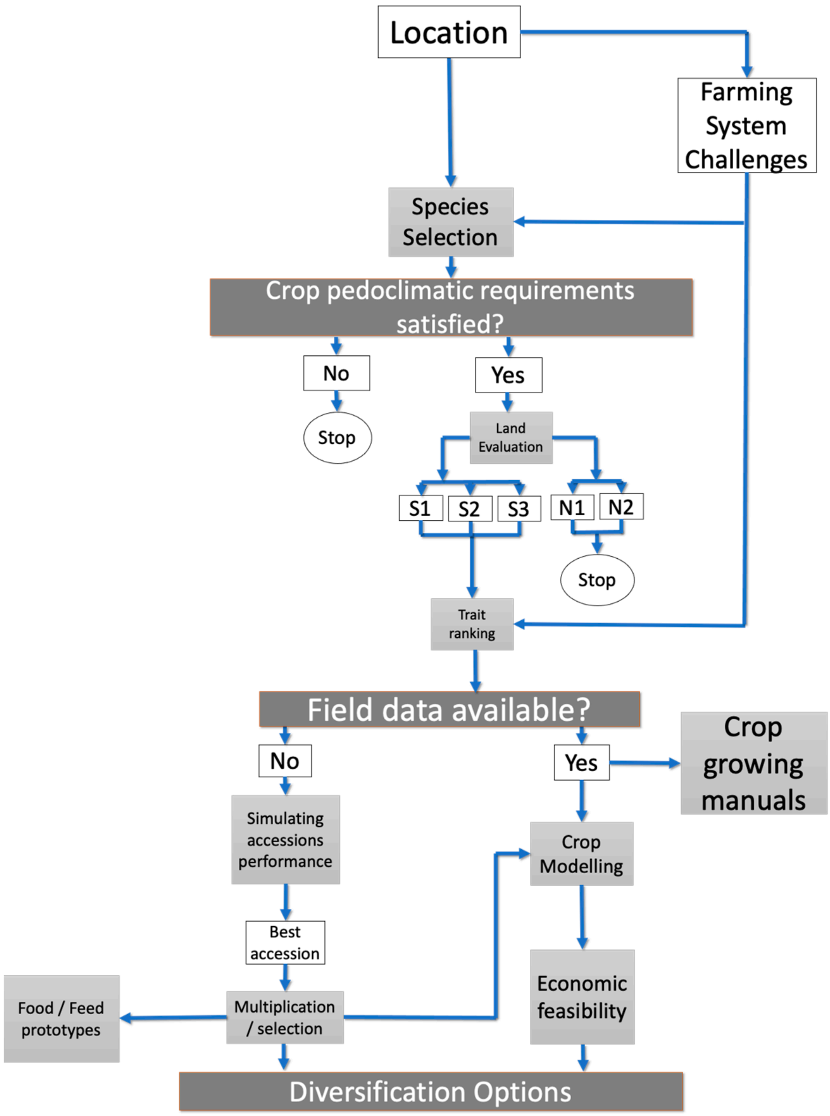

Figure 3. A decision tree for crop analytical diversification (adapted with permission from Jahanshiri et al. (2020); Wimalasiri et al. (2021)) [25,34].

The advent of new technologies to collate and analyse big data and develop automated tools for local-scale insight generation has provided an immense opportunity for knowledge exchange between all stakeholders in agriculture [71]. Except for the literature analysis step that should be quality controlled (by experts), the rest of the analysis presented in this article can be built as tools (apps) for aiding decisions at the finest scales [11,72,73]. These tools can benefit from a degree of automation that is provided by the method presented in this article in combination with expert-based techniques presented for detailed land capability analysis for current future conditions presented by Bell et al. (2021) [18] and [17] expert-based shortlisting for crops that are tested within the UK by Knight (2023) [19] to make the decisions on the wider adoption of underutilised crops even more applicable, robust, and risk free.

5. Conclusions

Land evaluation for crop diversification requires systematic approaches to crop selection that enable suitability evaluation for a broad list of locally neglected and novel crops and ranking based on important traits and a sound evidence base. This will improve the utility of lands and can, in principle, lead to improvements in diets and resiliency of production systems. The present study attempts to help fill the gap by analysing the suitability of a large pool of crops using a well-known ecological niche assessment methodology. To further provide an evidence base for the priority list of crops, data on major traits including nutrition (macronutrients vitamins and minerals), resistance/tolerance (drought, frost, shade, saline and infertile soils, and pathogen/pest/weed resistance), physiological traits (water-use efficiency and potential yield), number of other uses, germplasm availability, and production knowledge were collected and utilised to rank the crops in each category (cereals, legumes, forage, fodder, vegetables, ornamental/landscaping, and industrial). Following the priority listing, crops with the highest potential were chosen, and a pathway for their adoption in UK production systems was proposed. The data that were collected for crop ranking are a valuable source of information for future studies involving crop diversification and will be inserted into a global knowledge base for underutilised crops and utilised in automated tools for land support.

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Appendix A

Table A1. The broad list of crops that are potentially suitable for the UK.

Highly_Suitable	Carrot	French Clover	Mountain Bromegrass	Sea Buckthorn (Hippophae Rhamnoides)	Wase
Acacia (Acacia anticeps)	Cashew	Frost Grass	Mountain Gum	Sea Buckthorn (Hippophae salicifolia)	Water Foxtail
Acacia (Acacia pachyacra)	Catnip	Galleta Grass	Mountain Rye	Sea Kale	Wattle
Acacia (Acacia pachycarpa)	Caucasian Clover	Gama Grass	Mulga	Sea Orach	Waxy Saltbush
Adzuki Bean	Cauliflower	Gama Medick	Murray Pine	Serradella	Weeping Lovegrass
African Bermudagrass	Chamborote	Garden Angelica	Mutton Grass	Sesame	Weeping Myall
African Fleabane	Chamomile	Garden Burnet	Myall-gidgee	Sewan Grass	Western Australian Swamp She-oak
African Foxtail	Chebulic Myrobalan	Garden Orach	ked Oat	Seymour Grass	Western Wheatgrass
Alder	Chee Grass	Garden Pea	rbon Vetch	Shadscale	White Clover
Aleppo Pine	Chervil	Garden Thyme	rrow-leaved Peppermint 'subsp. radiata'	Shafshoof Ain Seela	White Fir
Algarrobo Blanco	Chestnut	Gardner Saltbush	rrow-leaved Peppermint 'subsp. robusta'	Sharp-crapped Mallee	White Ironbark
Algerian Oat	Chewing's Fescue 'var. commutata'	Gean	rrowleaf Trefoil	Sheep Fescue	White Lupin
Alkali Sacaton	Chickling Vetch	Ghilghoza Pine	Necklace-Pod Alyce Clover	Shining Gum	White Mustard
Almond	Chickpea	Giant Crowfoot	Needle Grass (Aristida penta)	Shoestring Acacia	White Pea
Alsike Clover	Chilean Strawberry	Giant Hopbush 'subsp. angustifolia'	Needle Grass (Stipa barbata)	Showy Milkweed	White Peppermint
American Beachgrass	Chi Jute	Giant Wildrye	Needle Grass (Stipa breviflora)	Shrubby She-oak	White-tip Clover
American Beech	Chinese Pear	Gidgee	Needle Grass (Stipa caucasica)	Siberian Wheatgrass	Whitewood
American Licorice	Chinese Pine	Gimlet	Needle Grass (Stipa grandis)	Side-oats Grama	Wild Celery
American Sloughgrass	Chinese Tamarisk	Globe Artichoke	Needle Grass (Stipa krylovii)	Silver Wattle	Wild Crab
Amethyst' Purple Raspberry	Chives	Gobi Needle Grass	Nepalese Alder	Silvery Birdsfoot Trefoil	Wild Oat
Andean Lupin	Cicer Milkvetch	Golden Wreath Wattle	Nissi	Simon Poplar	Wild Strawberry
Annual Bluegrass	Cleistogenes chinensis	Goose Foot	Northern She-oak	Sii Meadow Grass	Wild Thyme
Annual Bristle Grass	Club Wheat	Gooseberry	Nussi	Slender Wheatgrass	Wimmera Ryegrass
Annual Ryegrass	Coast Green Wattle	Goosefoot	Oat	Slough Grass	Wolf Needle Grass
Argan	Cocksfoot	Grecian Foxglove	Oca.	Small Buffalo Grass	Wool Grass
Arizo Cypress	Cogwheel Medick	Green Arrow Arum	Ochrus Vetch	Small Reed Mace	Woolly Clover
Arundinella Grass (Arundinella hirta)	Colonial Bentgrass	Green Cabbage	Oldman Saltbush	Small-flowered Feather Grass	Yacon
As Tree	Common Club-rush	Green Spich	Onions 'var. cepa'	Smilograss	Yapunyah
Asparagus	Common Elder	Hairy-stem Gooseberry	Onobrychis scrobiculata	Smooth Brome	Yellow Alfalfa
Athel Tree	Common Foxglove	Hard Fescue	Painted Daisy	Smooth Pigweed	Yellow Bluegrass

Table A1. *Cont.*

Highly_Suitable	Carrot	French Clover	Mountain Bromegrass	Sea Buckthorn (Hippophae Rhamnoides)	Wase
Australian Beech	Common Kidney Vetch	Harding Grass	Pangola Grass	Ske Wood	Yellow Box
Ayacahuite Pine 'var. brachyptera'	Common Myrtle	Hardy Kiwi	Papaw	Soliane	Yellow Lupin
Balsam Fir	Common Plum	Hare's-foot Clover	Parsnip	Sorghum	Yellow Marsh Marigold
Bano	Common Red Ribes	Hartweg's Pine	Pecan	Sour Cherry	Yellow Sweet Clover
Bard Vetch	Common Reed	Hazel Nut	Pepper Tree	Southernwood	York Gum
Bardi Bush	Common Sunflower	Hemp/Marijua	Peppermint	Spanish Broom	Zig-zag Clover
Barley	Common Vetch	Hemp/Marijua 'var. indica'	Perennial Ryegrass	Spear Wattle	
Barnyard Grass	Common Wheat	Himalayan Cypress	Perennial Veldtgrass	Spelt Wheat	
Barrel Medick	Common Yellow Melilot	Himalayan White Pine	Persian Clover	Spotted Bur Clover	
Basin Wildrye	Coobah/Swamp Wattle	Holly Oak	Persian Poppy	Standard Crested Wheatgrass	
Bay Leaves	Coolibah	Hoop Pine	Ponderosa Pine	Sterile Oat	
Big Bluestem	Coovittra Wattle	Hop	Poppy	Stiff Hair Wheatgrass	
Bigleaf Mint	Coriander	Hop Clover	Pot Marigold	Strand Medick	
Bilsted	Couch Grass	Hordeum brevisubulatum	Potato	Strawberry	
Bird's-foot Trefoil	Cranberry	Horehound	Powderbark Wandoo	Strawberry Clover	
Bitter Potato	Creeping Bentgrass	Horseradish	Prairie Junegrass	Streambank Wheatgrass	
Bitter Vetch	Creeping Foxtail	Hungarian Vetch	Pretty Birdsfoot Trefoil	Subterranean Clover	
Black Bentgrass	Crested Wheatgrass	Hyacinth Bean	Puccinellia tenuiflora	Sugar Beet	
Black Box	Cucumber Tree	Hyssop	Pumpkin	Sugar Maple	
Black Gidgee	Cupped Clover	Idaho Fescue	Purple Vetch	Sulla	
Black Gram	Curly Dock	Intermediate Wheatgrass	Quackgrass	Sulla Annuel	
Black Medick	Cut-tail Gum	Irrara	Quail Bush	Sulla Epineux	
Black Mustard	Cutleaf Clover	Jammi (Prosopis cineraria)	Quandong	Sulla Pale	
Black Oak	Dandelion	Jammi (Prosopis spicigera)	Quince	Sulla Rose	
Black Oak 'subsp. pauper'	Desert Gum	Japanese Apricot	Quinoa	Sumol Grass	
Black Raspberry	Desert She-oak	Japanese Clover	Rapeseed	Sunn Hemp	
Black Saxaul	Desert Wattle	Japanese Mint 'var. piperascens'	Raspberry Jam Wattle	Swamp Gum	
Black Walnut	Deyeuxia angustifolia	Jerusalem Artichoke	Red Alder	Swamp She-oak	
Bladder Saltbush	Dhok	Joint Vetch	Red Clover	Swede	
Bladder-pod	Dill	Jungle Rice	Red Current	Sweet Acacia	
Blessed Thistle	Dundas Mahogany	Kaliptis	Red Fescue 'var. Rubra'	Sweet Belladon	
Blue Grama	Dune Wattle	Kangaroo Grass	Red Ironbark	Sweet Clover	
Blue Grass	Durango Pine	Karira Tree	Red Mallee	Sweet Pumpkin	
Blue Lupin	Durum Wheat	Kentucky Bluegrass	Red River Gum	Sweet Wormwood	
Blue Lupine	Dwarf Feather Grass	Kenya White Clover	Red Wattle	Sweet-pitted Grass	
Blue Panic	Dyer's-greenweed	Kharsu Oak	Redwood	Sydney Blue Gum	
Blue Wildrye	Eelgrass	Korshinsk Pea Shrub	Reed Cary-grass	Tagasaste	
Bluebunch Wheatgrass	Egyptian Clover	Kosso	Reed Mace	Tall Fescue	
Bluejack Oak	Egyptian Thorn	Lamb's-quarters	Rhodes Grass	Tall Wheatgrass	
Bodalla Wattle	Eilig	Latzs Wattle	Rhubarb	Tamarugo	

Table A1. *Cont.*

Highly_Suitable	Carrot	French Clover	Mountain Bromegrass	Sea Buckthorn (Hippophae Rhamnoides)	Wase
Boer Lovegrass	Emmer	Least Hop Clover	Ricegrass	Tarragon	
Borage	English Walnut	Leatherwood	Rock She-oak	Tauri Wheatgrass	
Bramble Wattle	Eragrostis pilosa	Lecheguilla	Rocket	Teff	
Brigalow	Esculent Birdsfoot Trefoil	Lehmann’s Love Grass	Rocoto Pepper	Thickspike Wheatgrass	
Brown Bentgrass	Esparto	Lentil	Rooikrans	Thousand Head Kale	
Brussels Sprouts	Europaen Beachgrass	Liquorice	Rose Clover	Tifton Medick	
Buffalo Gourd	European Beech ‘subsp. sylvatica’	Littleleaf Caraga	Rosemary	Tiger Nut	
Buffalo Grass (Buchloe dactyloides)	European Larch	Lovage	Rottnest Island Pine	Timothy	
Bulbous Barley	European Oregano	Low-bush Blueberry	Rough Bluegrass	Tobacco	
Bulbous Bluegrass	European Pennyroyal	Luzerne Escargot	Rough Grass	Tobosa Grass	
Bullamon Lucerne	European Raspberry ‘subsp. idaeus’	Maca Root	Russian Brome Grass	Tomato	
Bur Clover	Exotheca	Maharukh	Russian Olive	Tree-of-heaven	
Burrows Wattle	False Acacia	Mallee	Russian Wildrye	Trifolium pilulare	
Bushgrass	Fava Bean	Mallee Pine	Rye	Triple awned grass	
Bushman’s Tea	Feather Grass	Marsh Bird’s-foot Trefoil	Safflower	Triticale	
Bushveld Sigl Grass	Fennel-flower	Mashua	Saffron	Turnip Rape	
Butter Bur	Fenugreek	Meadow Fescue	Sage	Ulluco	
Caley Pea	Field Clover	Meadow Foxtail	Sainfoin	Umbrella Mulga	
California Bur Clover	Fig Plant	Meadow Oat Grass	Salix gordejevii	Umbrella Thorn (Acacia tortilis)	
Calvary Clover	Filbert	Meadow Saffron	Salmon Gum Tree	Vanilla Grass	
Cada Bluegrass	Fine Stem Stylo ‘var. intermedia’	Meadowfoam	Salsify	Variegated Alfalfa	
Cada Wildrye	Finger Millet	Mediterranean Orchard Grass ‘subsp. hispanica’	Salt River Mallet	Vasey Grass	
Cary Grass	Fish Hook Wattle	Mexican Tea	Salt Wattle	Velvet Bentgrass	
Canihua	Flat-topped Yate	Minni Ritchi	Sand Bluestem	Velvet Hill Wattle	
Canyon Live Oak	Flax	Mohru Tree	Sand Love Grass	Victoria Spring Mallee	
Caper (Capparis spinosa)	Forest Red Gum	Mongolian Pines ‘var. mongholica’	Sandplain Wattle	Virginia Strawberry	
Caraway	Fourwing Saltbush	Mongolian Wheatgrass	Scallion	Vuda Blue Grass	
Cardoon	Foxtail Millet	Mooh	Schilf	Wandoo	
Cardyne Vetch	French Bean	Mountain Brome	Scotch Pine	Wanza	

Table A2. Nutrition data and detail ranking.

Crop	Carbohydrate	Rank	Protein	Rank	Fat	Rank	RS_Nut	Rank_Nut	Vitamin A	Rank	Vita B1	Rank	Vita B2	Rank	Vita B3	Rank	Vita C	Rank	RS_Vit	Rank_Vit	Calcium	Rank	Iron	Rank	Phosphorus	Rank	RS_Min	Rank_Min	RS_Nutrition	Rank_Nutrition
Triticale	72.13	2	10.4	2	0	0	4	2	0	0	0.42	2	0.133	2	1.43	2	0	0	6	2	37	1	332	1	0	0	2	1	5	2
Bulbous Barley	73.48	1	12.5	1	0	0	2	1	6.6	1	0.65	1	0.29	1	4.6	1	0	0	4	1	33	2	3.36	2	264	1	5	2	4	1
Colonial Bentgrass	69.67	1	14.76	2	2.5	2	5	1	0	0	0	2	0	0	0	0	0	0	2	2	33	2	2.67	2	332	1	5	1	4	2
Brown Bentgrass	69.67	1	14.76	2	2.5	2	5	1	0	0	0	2	0	0	0	0	0	0	2	2	33	2	2.67	2	332	1	5	1	4	2
Dune Wattle	63.7	3	20.3	1	5.2	1	5	1	0	0	0.04	1	0	0	BDL	0	0	0	1	1	141	1	4.8	1	227	3	5	1	3	1
Tall Wheatgras	0.0001	4	24.5	1	0.06	4	9	4	16.42	2	0.08	4	0.13	4	0.0011	4	0.22	3	17	4	428	1	24.8	1	400	1	3	1	9	4
Reed Mace	51	1	6.7	4	2.3	3	8	3	24	1	0.321	2	0.448	2	0.001	3	21	2	10	2	252	2	14	3	110	2	7	2	7	2
Sulla Rose	8.3	3	14.3	2	3.2	2	7	2	0	0	580.5	1	445.5	1	0.41	2	310	1	5	1	1.63	4	20	2	0.26	3	9	4	7	2
Russian Wildrye	48.3	2	8.5	3	3.3	1	6	1	0	0	0.32	3	0.25	3	4.27	1	0	4	11	3	73	3	2.83	4	0	0	7	2	6	1
Sea Buckthorn	324.8	1	4.55	1	4.43	1	3	1	296	1	0.14	1	30.9	1	0.7	1	7280	1	5	1	192.5	1	39.9	1	0	0	2	1	3	1
Quandong	29.95	2	2.25	2	0	2	6	2	0	0	0.04	2	0	0	0	2	20	2	6	2	28	2	3.48	2	20.35	1	5	2	6	2
Spear Wattle	63.7	1	20.3	1	5.2	1	3	2	0	0	0.04	1	0	0	0	0	0	0	1	1	141	1	4.8	1	227	1	3	1	4	1
Bramble Wattle	78.4	1	18.56	3	4	2	6	2	0	0	0.04	3	0	0	0	3	0	3	9	3	0	0	2.2	3	0	0	3	1	6	2
Blue Lupine	26.6	3	41.4	1	5.4	1	5	1	0	0	0.53	1	0.28	1	3.24	2	0.04	2	6	2	150	1	6.15	1	740	1	3	1	4	1
White Pea	55.15	2	26.5	2	0.2	3	7	3	30	1	0.48	2	0	0	3.4	1	1	1	5	1	60	2	5.4	2	0.49	2	6	3	7	3
Scallion	9.34	1	1.1	1	0.1	1	3	1	0.001	1	0.046	1	0.027	1	0.116	1	31.2	1	5	1	23	1	0.21	1	0	0	2	1	3	1
Sandplain Wattle	63.7	3	20.3	1	5.2	1	5	1	0	0	0.04	1	0	0	0	0	0	3	4	2	141	3	4.8	3	227	1	7	3	6	3
Shoestring Acacia	87.05	1	0.5	2	0.13	2	5	1	0	0	0	2	0	0	0	0	13.18	1	3	1	366.37	1	25.41	1	2.96	2	4	1	3	1
Coonavittra Wattle	87.05	1	0.5	2	0.13	2	5	1	0	0	0	2	0	0	0	0	13.18	1	3	1	366.37	1	25.41	1	2.96	2	4	1	3	1
Velvet Bentgrass	69.68	1	14.76	1	2.5	1	3	1	0	0	0	0	0	0	0	0	0	0	0	0	33	1	2.67	1	332	1	3	1	2	1
Onions 'var. cepa'	0.34	2	1.1	2	0	0	4	2	2	2	0.046	2	0.027	2	0.116	2	7.4	2	10	2	23	1	0.21	2	29	1	4	1	5	2
Ochrus Vetch	52.3	1	34.6	1	0	0	2	1	3.49	1	0.46	1	0.23	1	1.64	1	13.5	1	5	1	0.0095	2	0.782	1	0.043	2	5	2	4	1

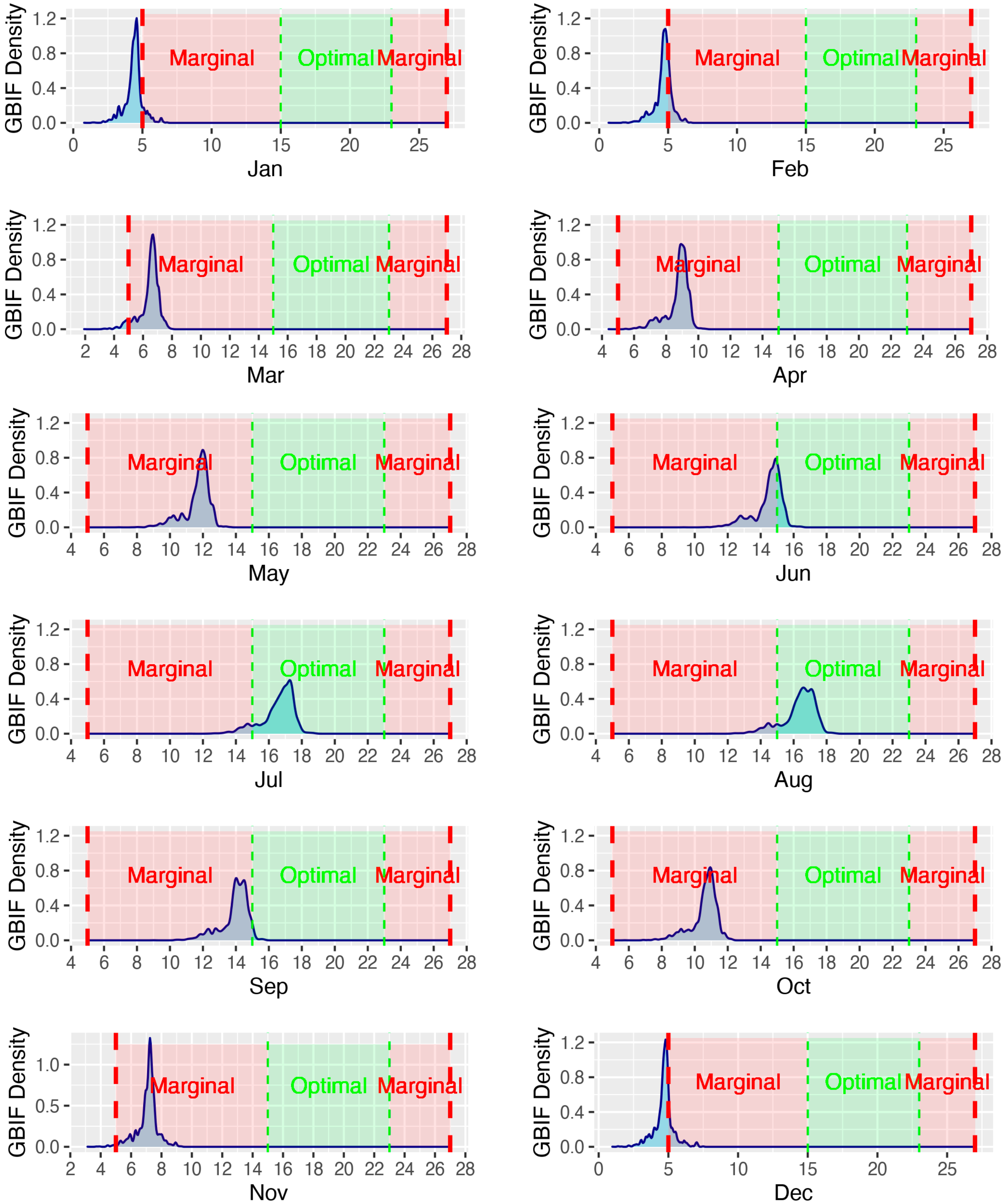

Figure A1. Seasonal suitability of wheat in the UK.

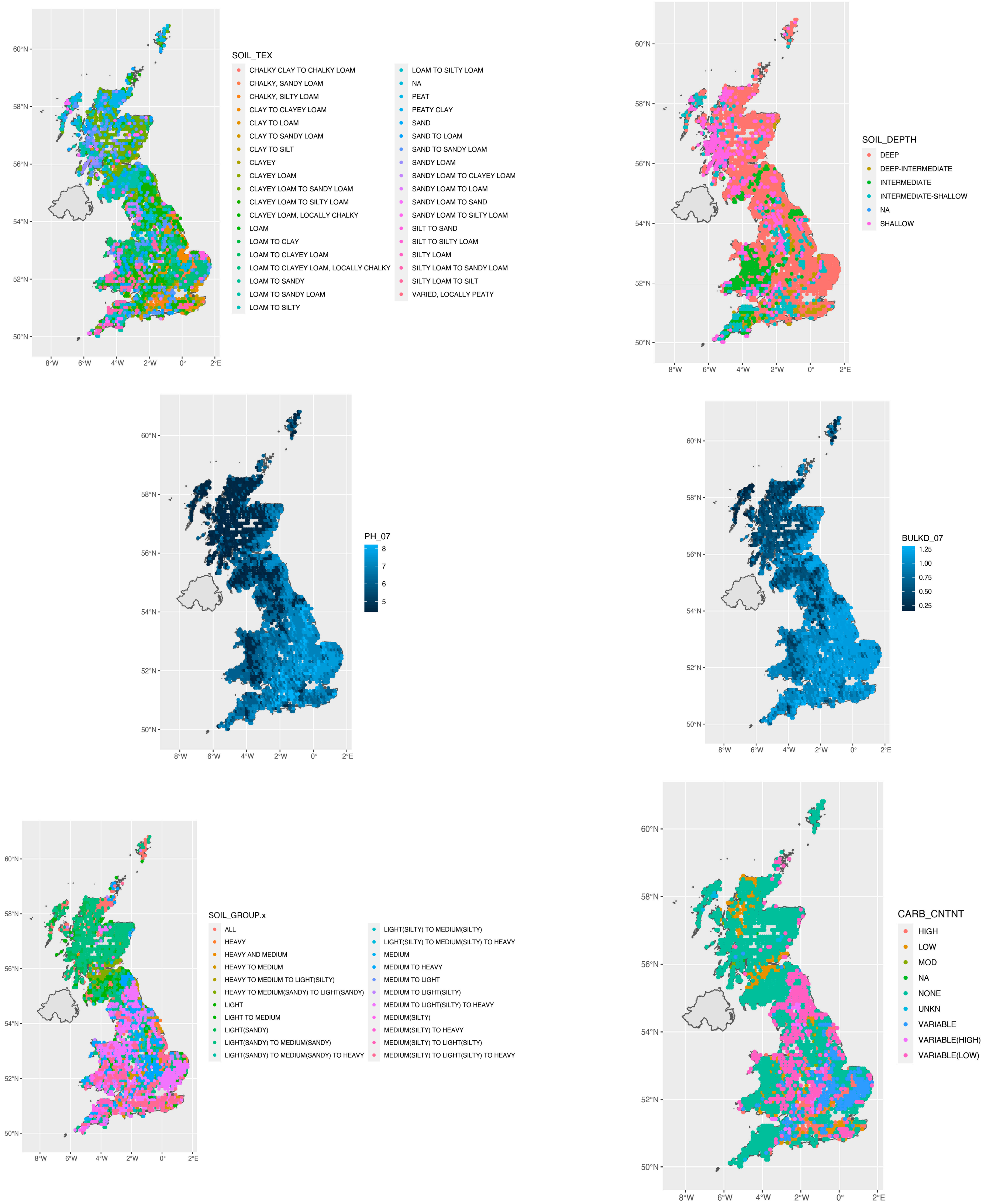

Figure A2. Soil texture map of UK (data from [52]).

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