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Detailed Crop Suitability Maps and an Agricultural Zonation Scheme for Malawi: Spatial Information for Agricultural Planning Purposes, by Todd Benson, Athur Mabiso, and Flora Nankhuni. A NAPAS:Malawi Working Paper.

The New Alliance Policy Acceleration Support-Malawi (NAPAS:Malawi) project has published online this Working Paper. The complete document is described and can be downloaded from the following webpage: <http://www.ifpri.org/publication/detailed-crop-suitability-maps-and-agricultural-zonation-scheme-malawi-spatial>

However, as the full document contains 59 high-resolution maps of Malawi that present the varying suitability of the land for producing a range of crops under different management practices and 16 tree species, the complete digital document is over 160 MB in size. In order to make available to readers who face high costs or other constraints in accessing digital materials online, an 'exploded' version of the document has been created on the same webpage to allow readers to choose which maps and other components of the NAPAS:Malawi Working Paper they wish to download.

This file contains one of these components.

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New Alliance Policy Acceleration Support-Malawi (NAPAS: Malawi)

DETAILED CROP SUITABILITY MAPS AND AN AGRICULTURAL ZONATION SCHEME FOR MALAWI

Spatial information for agricultural planning purposes

By

Todd Benson, Athur Mabiso, and Flora Nankhuni



Food Security Policy Innovation Lab Research Papers

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The high-resolution crop and tree species suitability maps included in this document are the outcome of over twenty years of efforts that find their origin with the rich set of analogue spatial information resources produced by the Malawi Land Resources Evaluation Project (LREP). This project was implemented over the period 1988 to 1992 by the government of Malawi, the United Nations Development Programme (UNDP), and the Food and Agriculture Organization of the United Nations (FAO) project and involved international experts working with staff of the then Land Husbandry Branch of the Ministry of Agriculture to undertake a close reconnaissance of the agro-ecological resources of Malawi. Extensive field work was done to map the soils across the country. Much of the climate data that has been collected since early in the colonial period was analyzed to map the agro-climatological zones of Malawi. Aerial photography was acquired and used to map land use and land cover across the country. From this research, analogue maps at the relatively detailed scale of 1:250,000 (1 cm = 2.5 km) were produced by LREP for each of the eight Agricultural Development Divisions (ADD) of the country, including maps of soils, agro-climate zones, land use and land cover, and suitability maps for a relatively restricted set of crops.

Efforts started in 1995 to convert the analogue information that was produced by LREP into digital format. A digital national agroclimate map and digital soils maps for several ADDs were produced by the first author and his colleagues at the Chitedze Agricultural Research station outside of Lilongwe. This process advanced significantly in 2000 with the digitization of all of the LREP soils and land use and land cover maps by the DANIDA-funded District and National Land Management Mapping Project in which Mr. Geoffrey C. Mzembe of the Department of Surveys and technical advisor Mr. Kent Burger played key roles. The effort to recreate the crop and tree species suitability maps began in earnest in 2014 under the NAPAS:Malawi project. This involved overlaying the national digital soils and agro-climate zones maps to create a national land unit map. Mrs. Sophie Nambuzi was responsible for creating a digital file of the contents of the eight detailed ADD analogue tables on the suitability of each land unit in each ADD for production of the 59 crop and tree species considered by the LREP team. Throughout this work, Mr. Stephen J. Nanthambwe, a member of the original LREP team, has been a willing advisor and repository of institutional knowledge on how these land resource information products originally were produced.

This document and the crop suitability maps it contains find their origins in LREP. We emphasize and acknowledge the immense, but underexploited, potential of the outputs of that project for guiding agricultural development planning in Malawi. In addition, the contributions of the colleagues mentioned above and the projects on which they worked are gratefully recognized. They are the authors of the crop and tree species suitability maps presented in this document to the same degree as are the authors of this working paper.

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Executive Summary

Although relatively small, Malawi is a country with significant agro-ecological diversity reflecting the diverse landforms associated with the Great Rift Valley that runs the length of the country. The effects of those landforms on soil formation processes, local climates, the distribution of water resources, and vegetation patterns results in a variety of quite complex farming systems across Malawi that farmers have developed to exploit distinct combinations of local agricultural resources. One important implication of this variety of farming systems is that the comparative advantage of different areas of Malawi for the production of different crops, livestock, and other agricultural products, whether for commercial purposes or for household food security, will differ significantly from place to place. In consequence, any agriculture plans that assume that a single technical approach to improving agricultural productivity and increasing the economic returns that households receive from their agricultural livelihoods will fail in many places. In designing agricultural development policies for the country, the geographic diversity of Malawian agriculture needs to be considered.

This document describes a two-level agricultural zonation scheme to guide agricultural planning in Malawi. This scheme combines broad agricultural development domains – based upon a district-level analysis of agro-ecological potential; physical access to market; and population density – with an extensive set of detailed, more locally relevant crop suitability maps to determine where agricultural development investments might best be located within a relevant development domain.

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INTRODUCTION

The identification of spatial zones to guide agricultural development planning in Malawi is an idea that has been proposed regularly in recent years. Although relatively small, Malawi is a country with significant agro-ecological diversity reflecting the diverse landforms associated with the Great Rift Valley that runs the length of the country. The effects of those landforms on soil formation processes, local climates, the distribution of water resources, and vegetation patterns results in a variety of quite complex farming systems across Malawi that farmers have developed to exploit distinct combinations of local agricultural resources.

One important implication of this variety of farming systems is that the comparative advantage of different areas of Malawi for the production of different crops, livestock, and other agricultural products, whether for commercial purposes or for household food security, will differ significantly from place to place. In consequence, any agriculture plans that assume that a single technical approach to improving agricultural productivity and increasing the economic returns that households receive from their agricultural livelihoods will fail in many places. In designing agricultural development policies for the country, the geographic diversity of Malawian agriculture needs to be considered.

Recognizing the need for greater attention to the differing agricultural development potentials across Malawi in planning investments and interventions in the agricultural sector, in its policy commitments under the New Alliance Country Cooperation Framework for Malawi, which was signed in December 2013, the government committed itself to “agricultural zoning based on priority crops and growth clusters and promotion of anchor farms as well as out grower schemes (commitment 3.2)”. This document describes a two-level agricultural zonation scheme for Malawi – one that combines broad agricultural development domains based upon a district-level analysis with an extensive set of detailed, more locally relevant crop suitability maps to determine where agricultural development investments might best be located within a relevant development domain.

The objective in developing this zonation scheme primarily is to guide broad, strategic thinking on where specific investments and development programs, both public and private, could best be placed across Malawi to promote increased commercialization of agricultural production. Given this objective, the zonation scheme needs to reflect both the variability in agricultural productivity across Malawi, which is based on agro-ecological conditions, and the different commercial opportunities available to producers due to differing levels of physical access to markets. Not only are we interested in whether an agricultural commodity can be produced in an area, we also need to consider whether farmers there will consistently be able to produce the commodity in a *profitable* manner.

The approach of this agricultural zonation scheme is first centered on establishing ***agricultural development domains*** for Malawi. These domains are defined by how three key factors that determine the comparative advantage of broad areas of the country for the commercial production of agricultural commodities intersect spatially – specifically, broad agro-ecological potential; physical access to market; and population density.¹

After having defined six different development domains for the country, we then extend the analysis to a more local scale. This involves bringing into the planning process spatial information on the varying agro-ecological suitability at local, sub-district level for the production of a range of different crops – ***crop suitability maps***. High-resolution suitability maps for 24 crops grown by smallholders using improved management practices, 18 rain-fed crops grown by smallholders under traditional management practices, for irrigated rice, and for 16 tree species are presented in the Annex of this document.²

AN AGRICULTURAL DEVELOPMENT DOMAIN SCHEME FOR FIRST-LEVEL AGRICULTURAL PLANNING IN MALAWI

Having a good understanding of how agricultural development potential varies across Malawi can be important within the context of agricultural planning for several reasons:

¹ The development domain approach has been used in several countries in Africa to spatially assess in each how best their varying, spatially-defined potentials for agricultural development could be exploited. For a detailed explanation of the approach, see Chamberlin, Pender, & Yu (2006).

² Digital versions of these maps are available upon request. The digital versions allow for analysis at a higher visual resolution than do the printed versions in this document.

- Spatial targeting of development initiatives in agriculture, rural transport, and market infrastructure;
- Guiding the location of private investment in agriculture, primarily through public sector planners identifying where incentives can best be placed to most profitably attract such investment;
- Investigating areas of expansion for commercial crop production, particularly high-value crops; and
- Examining the current binding constraints to increasing the scale of commercial agriculture in an area, particularly constraints that may be solved through public action and investments.

A relatively rich set of detailed spatial data has been developed for Malawi over the years that could guide agricultural planning – this includes information on soils, climate, and agroecological zones; natural vegetation; crop suitability; livelihoods, household food economies, and vulnerability zones; and a wide range of social and welfare variables.³ However, we need to be cautious about incorporating too many variables into how we define our agricultural development domains. If they are too complex or too local in their application, they will not be suitable for broad, national-level planning purposes to establish overall directions for policy and strategy development.

If our interest is to develop strategies for increased agricultural commercialization, agricultural development domains should be defined in a manner that reflects the principal determinants of spatial variation in agricultural commercialization potential across Malawi, while minimizing complexity and the inclusion of unnecessary information insofar as possible. The intersection of three principal determinants broadly enable or constrain various agricultural production and commercialization options in any area:

1. The *agricultural production potential* of an area based on its agro-ecological endowments in terms of climate, soils, and dominant landforms. This factor determines what agricultural products and how much of them might be produced in an area.
2. *Access to markets*, both agricultural input and output markets. Even if two areas have similar agricultural production potential, any differences between them in terms of physical access to markets may result in different patterns of comparative advantage for the commercial production of specific agricultural products.
3. *Population density* – The optimal agricultural production possibilities of an area, both in terms of products and the technologies that are used in production, will be determined in part by the amount of labor relative to land available, particularly through determining the comparative advantage of labor-intensive agricultural production

The varying ways in which these three factors intersect spatially provides a broad, first-level assessment for where the production of different agricultural products and the technologies used in their production is likely to be profitable across Malawi, while also providing guidance on a strategic orientation for agricultural development in those areas. The aim of the development domain level in agricultural planning is to develop strategic orientations for agricultural development in Malawi that recognize spatial differences in the most promising agricultural development options to pursue across the country.

However, there are clear limits to the insights that can be gained. Two are noted here.

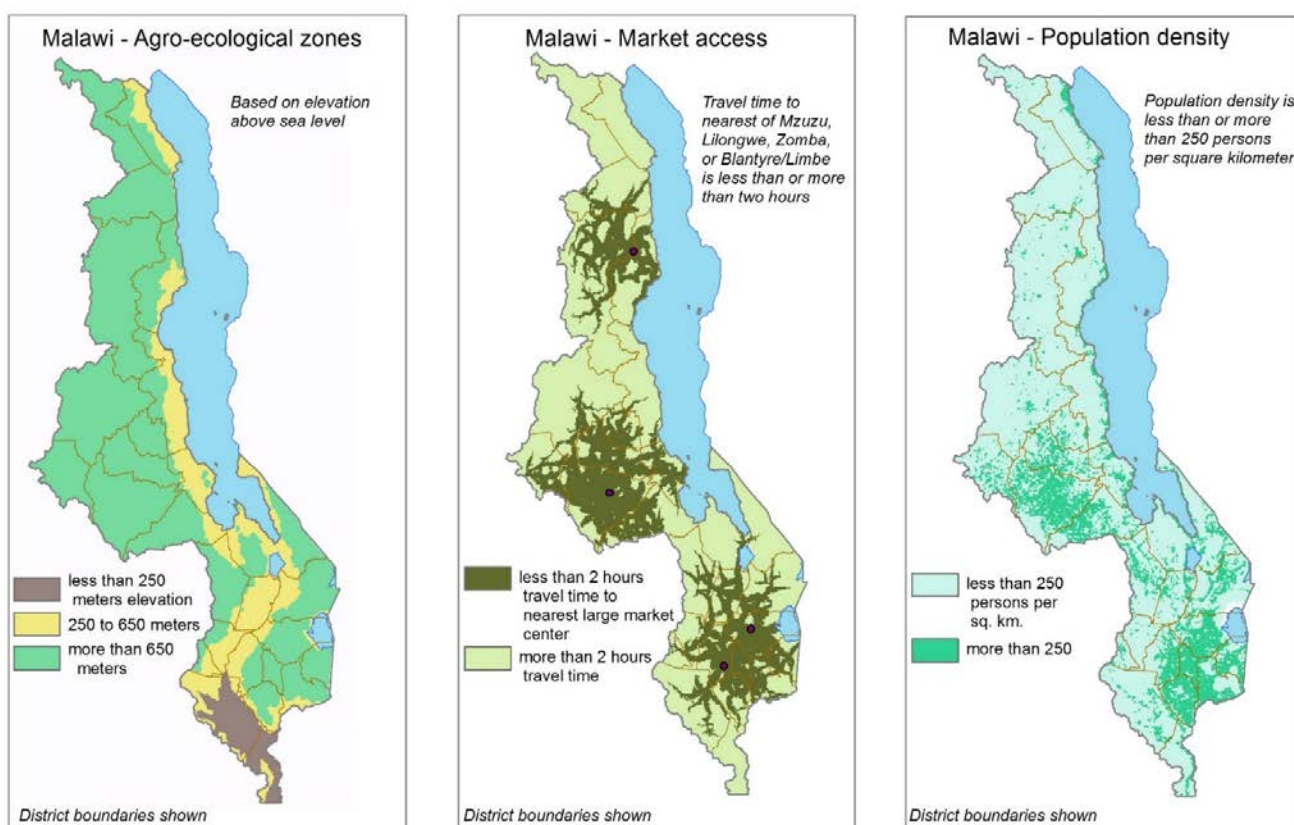
1. The insights that will be gained necessarily will be general. More detailed assessments of where commodity-specific investments should be located will require a more detailed and wider ranging set of spatial data than is used for defining the development domains. Later in this document we bring into the agricultural zonation scheme more detailed local information on agro-ecological factors that will guide how and where commodity-specific development efforts might be targeted – the crop suitability maps.
2. The focus of the development domains here is on agriculture. This zonation scheme for Malawi will provide only limited insights on the potential for other pathways to bring about sustained rural economic development, such as rural industry or other non-farm activities. However, given that the vibrancy of the non-farm rural economy in Malawi is to a large extent determined by the vibrancy of local agriculture, these development domains should also prove to be a useful secondary tool for general economic development planning beyond agriculture alone.

³ Among others, for spatial information on soils, climate, and agroecological factors, see the Malawi Land Resources Evaluation Project (LREP) studies from 1988-1992 described in more detail later in the paper, as well as Brown & Young (1965), Young & Brown (1962), and Stobbs (1971). For spatial information on livelihoods, see MVAC (2005), while for social and welfare variables, see Benson et al. (2002).

Agricultural production potential, physical market access, and population density in Malawi, the components used to define our agricultural development domains, are all continuously varying factors across space. In order to use them for planning purposes, each factor needs to be simplified, ideally into no more than two or three categories. The overlaying of the three categorized factors will generate unique development domains through the spatial intersection of the categories for each. Here, three agricultural production potential, two market access, and two population density categories will be used. From this combination, we could have up to 12 ($3 \times 2 \times 2$) development domains across the country. In consequence, defining the number of categories for each factor and, thereafter, the bounds for each category for a factor are central analytical tasks in developing development domains. We discuss each factor in turn.

In most countries a simplified agro-ecological zonation scheme often is already being used. For Malawi, agricultural researchers at Chitedze and Bvumbwe Agricultural Research Stations have long used an agro-ecological zonation scheme of three or four zones – the Lower Shire valley; the lakeshore plains and the Upper Shire valley; the mid-altitude plateau; and (sometimes) the highlands. This scheme primarily reflects differences between the zones in the amount, duration, and variability of rainfall and in their temperature regimes, while also incorporating some soil factors. Over decades of agricultural research, this geography has proven to be of value for guiding the development or refinement and targeting of new crop varieties or agricultural technologies. It makes sense to use the three-zone agro-ecological scheme as an input into defining the development domains for Malawi.⁴ The map at left in Figure 1 shows a proxy map for agro-ecological zonation based on elevation ranges. The map at left in Figure 2 shows the districts of Malawi categorized by in which of the three agro-ecological zones the majority of the populated areas of each district is found (gazetted areas and lakes were excluded from this analysis).

Figure 1: Underlying spatial data on agro-ecological zones, market access, and population density for constructing agricultural development domains for Malawi



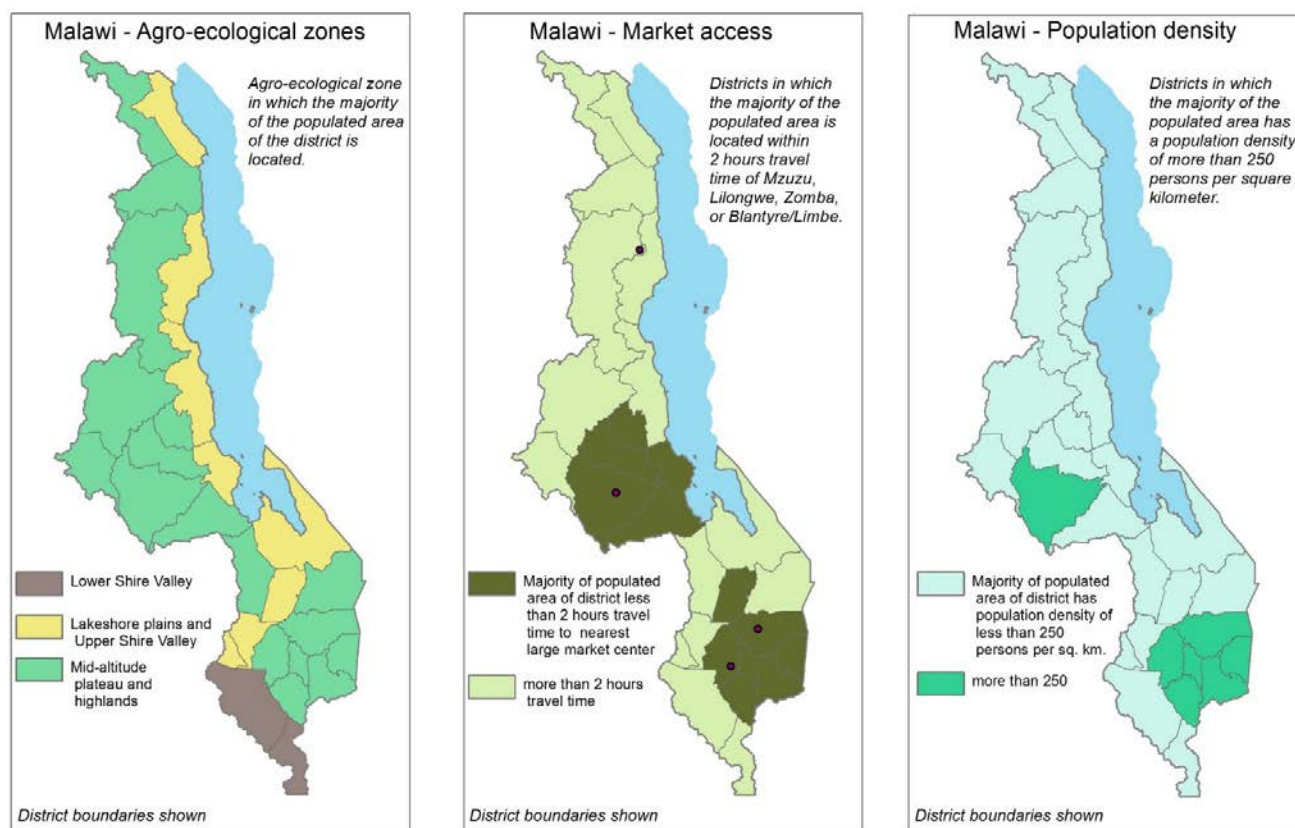
Source: Analysis by authors.

For the market access and population density factors in our agricultural development domain scheme, a conceptual understanding of how these two factors determine spatial patterns of agricultural production and commercialization activities can guide decisions on the number of categories in which to divide each factor. Generally there is a linear relationship between market access and the types of agricultural enterprises in which farmers profitably engage. Given the relatively small size of Malawi, two market access categories are likely sufficient. The measure we use to gauge market access also should be considered. While here, as shown in the center maps of Figures 1 and 2, travel time to the nearest market of a certain size is used, actual transportation-related transaction costs per unit of commodity or another measure could serve as an alternative

⁴ Doing so involves combining into a single zone the highlands and the mid-altitude plateau zones. This is reasonable since much of the highland areas are forests, national parks, or other gazetted areas that are not used for agriculture.

measure of market access. It also is important to recognize that the spatial marketing patterns for different agricultural products may be quite different. While major urban markets may be important market nodes for maize, for example, for other products, like milk or fresh vegetables, more local market centers likely would be more important.

Figure 2: District categorization by agro-ecological zones, market access, and population density for construction of agricultural development domains for Malawi



Source: Analysis by authors.

We use travel time to large, regional markets as our indicator of market access. The center map in Figure 1 shows a map of travel time to Mzuzu, Lilongwe, Zomba, and Blantyre/Limbe in which those areas more than two hours travel time are distinguished from areas closer to these market centers. This map of travel time was created by taking into account land cover types, slopes for areas without roads, and road quality for areas with roads. The center map in Figure 2 shows the districts of Malawi categorized by whether the average travel time from the populated areas of the district to any one of those four cities is more than or less than two hours. Alternative travel time thresholds for the two categories could be explored, as could patterns of access to smaller marketplaces than the largest markets in Malawi used here.

For the third factor we use to define our agricultural development domains, the population density factor, its relationship with agricultural production and commercialization patterns is more complex. Drawing upon theories first proposed by Boserup (1965), increasing population density is expected to induce agricultural intensification that will result in greater output per unit area of land, higher wage rates, and higher output prices, among other changes in production systems and household livelihoods. However, agriculture as a livelihood will increasingly no longer make economic sense as population densities increase towards urban conditions – in such contexts, any comparative advantage that agricultural livelihoods would have had in those agroecological conditions under lower population densities would be lost. Conceptually, certain types of agricultural livelihoods will no longer be sustainable at higher population density levels. Consequently to fully explore how population density might affect agricultural development potential in Malawi, three categories of population density likely would be best – using both high and low population density thresholds. However, in the interest of simplicity, here we only use two.

The map at right in Figure 1 shows a population density map from projected population figures for 2015 using a 250 persons/km² category bound. The map at right in Figure 2 shows the districts of Malawi categorized by whether the average population density in the populated areas of each district is more than or less than 250 persons/km². Recent analysis examining whether there is any evidence of agricultural intensification with increasing population density in Malawi found an increase in the gross value of crop output per hectare at population densities above 250 persons/km² (Ricker-Gilbert et al. 2014). Alternative population density bounds for the two categories could be explored, as could the value of the use of three categories, rather than two.

The resultant map of agricultural development domains for Malawi based on the intersection of the three agro-ecological zone categories, two market access categories, and two population density categories applied to the districts of the country is presented in Figure 3. As shown in Table 1, of the 12 domains possible from the intersection of three agro-ecological, two market access, and two population density categories, only six agricultural development domains for Malawi resulted from the analysis here.

Table 1: The six spatial intersections of agro-ecological suitability, market access, and population density which define the district-level agricultural development domains for Malawi

	Poor market access		Good market access	
	Low population density	High population density	Low population density	High population density
Lower Shire valley	2 districts			
Lakeshore & Upper Shire valley	7 districts		2 districts	
Mid-altitude plateau	7 districts		3 districts	7 districts

Source: Analysis by authors.

At more local scales, such as the Extension Planning Area (EPA) or the sub-district Traditional Authority (TA), more than six development domains may emerge from such an analysis, while at broader scales, such as for the eight Agricultural Development Divisions (ADD) of the country, fewer than six domains would result. Consequently, the most appropriate spatial unit of analysis for broad planning purposes – whether district or some other unit – is an important element to consider in deciding how to define the development domains. However, arguably the district-level spatial unit of analysis is the most broadly applicable, given that it is the principal development planning unit at sub-national level.

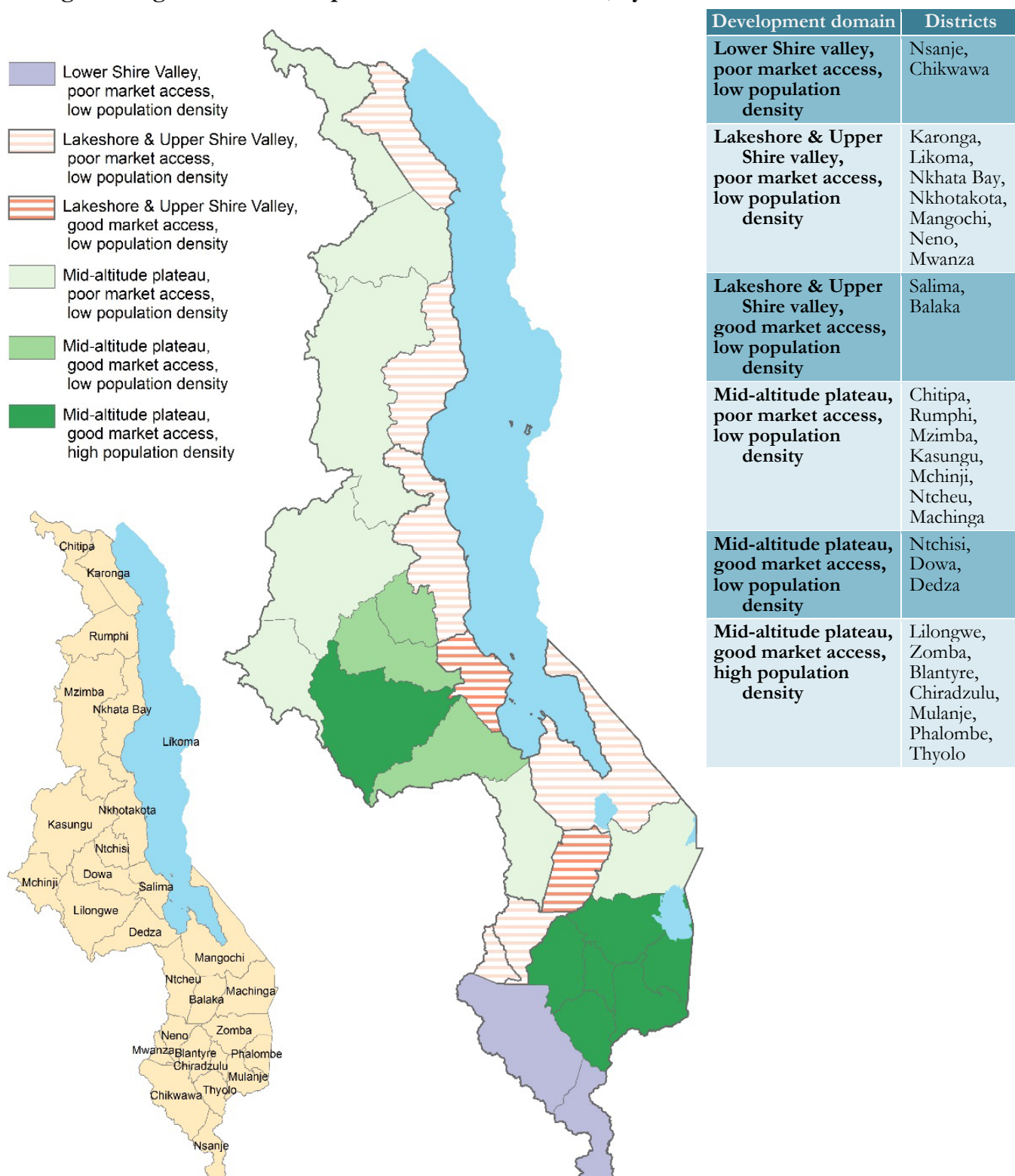
The agricultural development domains in Malawi presented in Figure 3 should be evaluated by a range of experts on agricultural production and marketing in Malawi to determine whether this development domains scheme provides a reasonable representation of the different agricultural development potential zones of the country and useful guidance on how that development potential might be exploited. Among the types of questions that experts should ask are:

- Are the boundaries shown between the development domains real and of value? For example, do Salima and Balaka districts, found in the same development domain, share much the same development potentials? Are these development potentials significantly different from those found in other districts located along the lakeshore or in the Upper Shire valley?
- Do Dedza, Ntchisi, and Dowa districts have any agricultural development potentials that are not found in adjoining Kasungu, Mchinji, and Ntcheu districts, and vice versa?
- Are the agricultural commercialization opportunities for farmers in the good market access with high population density areas of Lilongwe and the districts in the Shire Highlands really so different from opportunities available to farmers located elsewhere in Malawi?

Moreover, the factors that we use and the categories that we impose on each factor in order to define the agricultural development domains all must be evaluated by experts as these development domains are refined. In answering questions like those noted above, insights are gained into the strengths and weaknesses of each factor, the categories for each, and the types of planning applications to which this agricultural zonation scheme is suited and those for which it is unlikely to be of much use.⁵

⁵ As a complementary approach to using expert assessment to validate this agricultural zonation scheme for Malawi, an empirical method also can be used to refine the development domains. This involves testing through an analysis of variance (ANOVA) statistical approach how well various alternative development domain schemes explain specific observed agricultural, economic, or human development outcomes across Malawi. Such analysis can be used both for exploring alternative factors to consider in defining the development domains to the three used in this paper and for exploring the bounds of the categories of each factor used. See Chamberlin, Pender, and Yu (2006).

Figure 3: Agricultural development domains for Malawi, by district



Source: Analysis by authors.

SPATIAL CROP SUITABILITY ANALYSIS FOR DETAILED, SECOND-LEVEL AGRICULTURAL PLANNING IN MALAWI

With the development domains, one can begin thinking about what agricultural development options might be best suited for a particular domain and not for other domains. For example, intensive horticultural production would be best suited for areas of the mid-altitude plateau with high population density and good market access, while intensive fruit production may be best targeted in somewhat warmer areas of the lakeshore with good market access, as in Balaka and Salima, particularly if irrigation is a possibility. However, as soon as one starts considering technical aspects of the agricultural commercialization development possibilities in each development domain, other factors need to be brought into the analysis— such as irrigation in the case of fruit production in Balaka and Salima. Once the broad outline of spatially-informed agricultural development strategies is made clear through the use of the development domains, a second round of more detailed, sub-sector specific spatial analyses will then need to be done to determine the design of actions to be taken. In these analysis, we will need to draw upon a broader range of both spatial and non-spatial data.

Malawi has considerable information to guide specific analyses of the optimal locations for particular public investments for agricultural development, whether based on crops, livestock, or other agricultural activities. Capable analysts can work with a broad range of information resources from across the country to gain important insights on what sorts of agricultural and related activities should be promoted where to bring about significant increases in agricultural commercialization in Malawi.

For crop production, in particular, the Land Resources Evaluation Project (LREP) that was done in the period 1988 to 1992 provides Malawi with a rich spatial information resource for this purpose (Eschweiler et al. 1991; also see the eight Agricultural Development Division (ADD)-specific LREP reports, e.g., Nanthambwe & Eschweiler (1992) for Kasungu ADD; Paris (1991) for Blantyre ADD). To date, this information has not been exploited to guide the targeting of agricultural development programs and projects as much as it should have been. LREP was a joint government of Malawi, United Nations Development Programme (UNDP), and Food and Agriculture Organization of the United Nations (FAO) project that involved international experts working with staff of the then Land Husbandry Branch of the Ministry of Agriculture to undertake a close reconnaissance of the agro-ecological resources of Malawi. Extensive field work was done to map the soils across the country at the relatively detailed scale of 1:250,000 (1 cm = 2.5 km). Much of the climate data that has been collected since the early days of the colonial period was analyzed to map the agro-climatological zones of Malawi at the same geographic scale. Table 2 lists the information that was developed for each soil mapping unit in the LREP Soils and Physiography Map and for each agro-climate zone in the LREP Agro-climatic Zones Map.

Table 2: Information presented in the legends for the Soils and Physiography Map and the Agro-climatic Zones Map prepared by the Malawi Land Resources Evaluation Project, with categories

SOILS AND PHYSIOGRAPHY MAP				
Area	To the nearest 100 hectares			
Parent Material	<ul style="list-style-type: none"> fluvial, colluvial, or lacustrine sediments mafic (rocks with dark-colored (ferromagnesian) minerals) 	<ul style="list-style-type: none"> medium to fine-grained or mixed coarse to fine-grained sedimentary rocks coarse-grained sedimentary rocks 	<ul style="list-style-type: none"> felsic (rocks with light-colored minerals, such as feldspar and quartz) aeolian deposits 	
Slope	<ul style="list-style-type: none"> flat or almost flat (0 to 2%) gently sloping (2 to 6%) 	<ul style="list-style-type: none"> sloping (6 to 13%) moderately sloping (13 to 25%) 	<ul style="list-style-type: none"> steep (25 to 55%) 	
Soil Group	<ul style="list-style-type: none"> lithic vertic fluvic 	<ul style="list-style-type: none"> salic gleyic arenic 	<ul style="list-style-type: none"> mopanic calcaric paralithic 	<ul style="list-style-type: none"> dystric-ferralic eutric-ferralic dystric-fersialic eutric-fersialic
Soil Family	Identified from soil mapping fieldwork of the Land Resources Evaluation Project			
Depth	<ul style="list-style-type: none"> very deep (> 150 cm) deep (100 to 150 cm) 	<ul style="list-style-type: none"> moderately deep (50 to 100 cm) shallow (30 to 50 cm) 		
Drainage	<ul style="list-style-type: none"> very poor poor imperfect 	<ul style="list-style-type: none"> moderately well well somewhat excessive 	<ul style="list-style-type: none"> excessive 	
Particle size, topsoil, mean, upper 30 cm	<ul style="list-style-type: none"> coarse (<15% clay & >70% sand) coarse, skeletal medium (15 to 35% clay & <65% sand, or <15% clay & <70% sand) 	<ul style="list-style-type: none"> medium, skeletal fine (>35% clay) fine skeletal 	'Skeletal' applies with more than 35% of the soil by volume is made up of coarse mineral fragments with a diameter of more than 2 mm.	
Particle size, subsoil, mean, 30 - 100 cm	(As immediately above)			
pH (soil reaction), mean, upper 50 cm	<ul style="list-style-type: none"> very strongly acid (3.5 to 4.5) strongly acid (4.5 to 5.0) acid (5.0 to 5.5) moderately acid (5.5 to 6.0) 	<ul style="list-style-type: none"> slightly acid (6.0 to 6.5) almost neutral (6.5 to 7.0) very slightly alkaline (7.0 to 7.5) slightly alkaline (7.5 to 8.0) 	<ul style="list-style-type: none"> moderately alkaline (8.0 to 8.5) strongly alkaline (>8.5) 	
CEC (cation exchange capacity), mean, upper 30 cm, me/100 g	<ul style="list-style-type: none"> very low (<5) low (5 to 10) medium to very high (>10) 			
N (total Nitrogen), in %, mean, upper 50 cm	<ul style="list-style-type: none"> very low (<0.08) low (0.08 to 0.12) 	<ul style="list-style-type: none"> medium to very high (>0.12) 		
P (available Phosphorus), in ppm, mean, upper 50 cm	<ul style="list-style-type: none"> very low (<6) 	<ul style="list-style-type: none"> medium to very high (>18) 		

	•low (6 to 18)
K (exchangeable Potassium), in me/100 g, mean, upper 50 cm	•very low (<0.1) •medium to very high (>0.2) •low (0.1 to 0.2)
Color, subsoil	One or two of the Munsell soil color names
Surface stoniness and rockiness, cover %	•< 1% •> 15% •1 to 15%
Present erosion	•slight •severe •moderate
Flooding	•none •exceptional (only in years of •none to exceptional (very exceptionally high rainfall rarely, or only in the past) •frequent
Landform	One or more landforms drawn from a list of over 40 landform types, e.g., alluvial plains; dambos; dissected footslopes; inselbergs; low hills; marsh margins; valley sides; ridges in uplands; etc.
AGRO-CLIMATIC ZONES MAP	
LGP	Length of the growing period, in days. Period of the year in a location over which rainfall exceeds half of potential evapotranspiration, plus the period required to evapotranspire an assumed 100 mm of stored soil moisture.
P/PET	Ratio of precipitation to potential evapotranspiration over the growing period. Three classes are used: <1.0; 1.0 to 1.3; and >1.3. When the ratio is less than 1.0, crops are likely to suffer from water stress and soil moisture storage is usually very low. With the ratio between 1.0 and 1.3 there is still a chance of crops suffering from water stress for short periods. With a ratio of over 1.3, crops are unlikely to suffer from water stress during the growing period.
T-GP	Mean temperature during the growing period, in °C
P-an	Mean annual precipitation, in mm
DM	Mean number of dry months per year, i.e., months with less than 50 mm of precipitation
T-an	Mean annual temperature, in °C
T-min	Mean minimum temperature of the coolest month, in °C. July is the coolest month in most locations in Malawi.
T-EGP	Mean temperature during the last 120 days of the growing period, in °C

Source: Eschweiler et al. (1991).

The soils and agroclimate maps developed through the project were then overlaid to develop a 'land unit' map for each of the eight ADDs of Malawi. Each land unit is defined by a unique combination of relatively homogeneous soil and climate properties within its boundaries.

These land units were then used with information on the optimal soil and climate conditions for growing a range of rainfed agricultural crops, traditionally irrigated rice, and tree species to undertake a spatial suitability analysis for the production of each in each land unit. These optimal agro-ecological production conditions are listed for each of the crop suitability maps presented in the Annex of this document. In addition, for the rainfed crops, two different management regimes were considered (Eschweiler et al. 1991):

- Improved traditional management of rainfed crops – use of improved cultivars; application of inorganic fertilizer; possibly use hired labor or animal traction.
- Rainfed-cropping under traditional management practices – local crop varieties; no inorganic fertilizer.

For the crops and tree species listed in Table 3, information was generated for all of the land units in most of the eight ADDs of Malawi.

Table 3: Crops and tree species for which production suitability assessment by land unit were done by the Malawi Land Resources Evaluation Project

Rainfed-cropping under improved traditional management practices	Irrigated rice under traditional management and improved traditional management	Tree species	Rainfed-cropping under traditional management practices
<ol style="list-style-type: none"> 1. Maize – long cycle (6 ADDs) 2. Maize – short cycle (8) 3. Sorghum (8) 4. Finger millet (3) 5. Bulrush millet (5) 6. Wheat (6) 7. Cassava – long cycle (5) 8. Cassava – short cycle (5) 9. Irish potato (6) 10. Common (<i>Phaseolus</i>) bean – long cycle (6) 11. Common (<i>Phaseolus</i>) bean – short cycle (7) 12. Cowpea (6) 13. Groundnut – long cycle (7) 14. Groundnut – short cycle (8) 15. Soyabean (7) 16. Pigeonpea (7) 17. Sunflower (8) 18. Tobacco – air- and fire-cured (7) 19. Tobacco – flue-cured (5) 20. Cotton (7) 21. Tea (2) 22. Coffee (<i>Arabica</i>) (4) 23. Citrus (6) 24. Cashew (5) 	<ol style="list-style-type: none"> 1. Rice (Faya variety) (7 ADDs) 	<ol style="list-style-type: none"> 1. <i>Faidherbia albida</i> (8 ADDs) 2. <i>Senna siamea</i> (8) 3. <i>Gmelina arborea</i> (8) 4. <i>Azadirachta indica</i> (8) 5. <i>Callitris calcarata</i> (7) 6. <i>Callitris hugellii</i> (8) 7. <i>Melia azedarach</i> (8) 8. <i>Cordyla africana</i> (8) 9. <i>Eucalyptus camaldulensis</i> (8) 10. <i>Eucalyptus grandis</i> (7) 11. <i>Eucalyptus maidenii</i> (5) 12. <i>Eucalyptus tereticornis</i> (8) 13. <i>Pinus caribaea</i> (7) 14. <i>Pinus kesiya</i> (7) 15. <i>Pinus oocarpa</i> (3) 16. <i>Pinus patula</i> (7) 	<ol style="list-style-type: none"> 1. Maize (8 ADDs) 2. Sorghum (8) 3. Finger millet (4) 4. Bulrush millet (5) 5. Wheat (4) 6. Cassava (8) 7. Sweet potato (7) 8. Irish potato (5) 9. Common (<i>Phaseolus</i>) bean (7) 10. Cowpea (7) 11. Groundnut (8) 12. Soyabean (7) 13. Pigeonpea (8) 14. Guar bean (2) 15. Sunflower (8) 16. Cotton (6) 17. Citrus (4) 18. Cashew (4)

Source: Eschweiler et al. (1991).

Note: The number in parentheses is the number of ADDs out of the eight ADDs in which a suitability assessment was done for that crop or tree species. For the most common crops, suitability assessments were done in all eight ADDs. For less common crops and tree species, suitability assessments were only done in selected ADDs where they are found or may potentially be grown.

Four suitability classes were used in assessing the suitability of growing a particular crop on the land within a particular land unit – ‘Highly suitable’ (coded S1); ‘Moderately suitable’ (S2); ‘Marginally suitable’ (S3); and ‘Not suitable’ (N). These suitability classes are defined in Table 4. Three intermediate classes were also used to reflect differing production potential within complex land units that were characterized by more than one type of soil – S1/S2, S2/S3, and S3/N. However, in the maps presented in the Annex to this document, these intermediate classes for complex land units are not presented. The suitability classification for the dominant land unit in the complex land unit is presented instead.

Table 4: Definition of land suitability classes from the Malawi Land Resources Evaluation Project

Symbol	Suitability class	Definition	Potential yield as percentage of maximum attainable yield
S1	Highly suitable	Land having no significant limitations to the sustained production of the crop or tree species under consideration	80 to 100 percent
S2	Moderately suitable	Land having limitations which in aggregate are small to substantial to the sustained production of the crop or tree species under consideration. Production levels will be reduced or costs will be increased in comparison to ‘Highly suitable’ and ‘Moderately suitable’ land units on which the crop or tree species is produced such that it may be impracticable or uneconomic to produce the crop or tree species.	50 to 80 percent
S3	Marginally suitable	Land having limitations which in aggregate are severe to the sustained production of the crop or tree species under consideration. Production levels will be reduced or costs will be increased in comparison to ‘Highly suitable’ land units on which the crop or tree species is produced.	20 to 50 percent
N	Not suitable	Land having significant limitations which preclude any possibility of successful sustained production of the crop or tree species under consideration. In some cases, the land could be made suitable by major changes, such as through the use of intensive soil conservation measures.	less than 20 percent
S1/S2 S2/S3 S3/N	Intermediate classes	Land having intermediate suitability or in which the suitability is divided among the two classes	combination of above

Source: Eschweiler et al. (1991, p.12).

For land with a suitability classification lower than ‘Highly suitable’, the types of limitation to the production of the particular crop in question were also identified in the suitability analysis exercise – 11 different types of limitations on crop growth are considered. These limitations include those related to temperature and moisture, nutrient availability, rooting conditions, soil workability, erosion and flooding hazards, and soil toxicity or acidity. While these limitations are not presented in the maps in the Annex to this document, this information can be obtained in the LREP reports.

In the Annex to this Working Paper are 59 maps – for 24 crops produced under improved practices; 18 crops produced under traditional management practices; irrigated rice produced by smallholders; and 16 tree species – developed from the production suitability analysis that was conducted by LREP. Table 5 describes the differing attributes of the two crop management regimes considered in the suitability analysis

Table 5: Attributes of ‘traditional’ and ‘improved traditional’ crop management regimes employed by smallholder farmers in Malawi for the crop suitability analysis of the Malawi Land Resources Evaluation Project

Attribute	Traditional management	Improved traditional management
Production system	Rainfed cultivation of presently grown crop mixture	Rainfed cultivation of crops usually grown in pure stands
Technology employed	<ul style="list-style-type: none"> • Local planting materials • No inorganic fertilizers or chemical pest, disease, or weed control • Use of poorly aligned ridges with sub-optimal spacing or planting on the flat • Sub-optimal plant densities and generally poor cultivation practices 	<ul style="list-style-type: none"> • Improved planting materials (seeds, cuttings) • Early land preparation and timely planting • Limited use of fertilizers and pesticides. Composting and manuring. • Correct plant spacing and plant densities • Cultivation on correctly spaced contour-aligned cultivation ridges • Adequate weeding. • Extension advice is followed
Power source	Exclusive use of manual uncosted family labor with hand tools	Use of (hired) manual labor with hand tools or animal traction with improved implements
Labor intensity	High, but only family labor	High, family labor as well as hired labor
Capital intensity	Low, no use of credit	Intermediate, access to and use of credit facilities
Market orientation	Basically subsistence farming, although some cash crops may be grown	Subsistence production and commercial sale of cash crops and surplus food crops
Infrastructure requirements	Limited access to markets and agricultural services	Free access to market facilities and agricultural services
Land tenure	Customary land with traditional rights	Customary land with traditional rights
Land holdings	Small and usually fragmented	Small, but often consolidated
Recurrent inputs required	Traditional seed, human labor	Improved seed, human (costed) labor and animal power, fertilizers and pesticides

Source: Eschweiler et al. (1991, p.35).

There are two broad ways in which this locally relevant information can be used in the context of agricultural planning.

1. To guide the design of policies and programs to support those engaged in crop production in a particular targeted area, planners might review the results of all of the crop suitability analyses that were done for the land unit(s) in the targeted area. Such information will provide insights on whether the production of alternative crops to those currently being produced in this area might merit closer investigation. By coupling this spatial agro-ecological suitability information with the findings from commodity-specific market and value chain studies, planners would be able to determine whether farmers there might profitably produce any alternative crops to those they are current producing and how they would market them. The higher level agricultural development domain analysis would provide some initial guidance on commercialization potential.
2. For the planning of government initiatives to foster increased investment in the downstream value chains for specific crops, the crop suitability analysis could be used by planners to assist potential investors in determining from where they might source their raw materials. Such investors might conceivably seek to acquire land in agro-ecological suited areas if the commodities of interest lend themselves to a vertically integrated production, processing, and marketing business model. Alternatively, the planners could assist these investors in engaging with and supporting producers in areas suited for the production of the commodities in question to increase their production, either through contract farming

arrangements or by strengthening local markets so that the investors will be able to obtain sufficient commodities for their needs from local producers through those markets.

The crop suitability information from the LREP project provides considerably more detailed agro-ecological information than was used for deriving the development domains, allowing for crop-specific *production* assessments to be made. However, parallel crop-specific assessments of the *commercialization* potential for crops that are shown to be suitable for a particular area would need to be undertaken as part of this planning process. Such assessments would require investigating the marketing requirements of the crop, particularly in terms of the standards of crop quality sought by consumers and the perishability of the crop. Where an export market is foreseen for a crop, both the markets into which the crop will be exported and the administrative procedures for doing so will need to be considered. A range of value chain and basic market analysis approaches will be necessary to take the insights on potential production gained from the use of the development domain analysis and from the LREP crop suitability maps to determine whether the production of crops found to be suitable for production in an area can be produced profitably within a competitive market.

REFINING THE AGRICULTURAL ZONATION SCHEME

The development domains approach to defining agricultural zones should now be evaluated by experts on agricultural production and marketing in Malawi, particularly experts within the Ministry of Agriculture, Irrigation, and Water Development (MoAIWD), but also from other agricultural research and training institutions. In addition, quantitative analyses should be done to refine the definition of the development domains. Thereafter, the development domain scheme that seems to best reflect the development challenges in Malawi's agriculture sector and inform the approaches that might be taken to address them should increasingly be brought into agricultural planning discussions within the Ministry and more broadly within government.

Thereafter, the LREP spatial crop suitability information discussed in this paper should be more fully exploited than it has been to date. When it comes to planning public investments in to enhance agricultural production in Malawi, the further development of the agricultural zonation tools presented in this document should allow us to move away from any universally targeted policies and programs and better take into account in their design the geographic diversity of agriculture in Malawi.

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ANNEX – NATIONAL SUITABILITY MAPS FOR SELECTED CROPS AND TREE SPECIES

There are four groups of national suitability maps for selected crops and tree species developed by the Malawi Land Resources Evaluation Project:

1. Rainfed crops under improved traditional management practices (24 maps);
2. Irrigated rice under traditional management and improved traditional management (one map);
3. Tree species (16 maps); and
4. Rainfed crops under traditional management practices (18 maps).

These are presented in turn in this annex.

