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A GIS-based Analysis of the Likelihood of Adoption of Some Multi-purpose Tree species in East Africa

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Abstract

The Multi-purpose Tree (MPT) species have the ability to fit into the farming systems of the East African region where low agricultural productivity, widespread land degradation and hence a diminishing capacity to support the growing human and livestock population are major problems.
GIS has been used to develop a spatial representation of the recommendation domains of five MPT species (*Calliandra calothyrsus, Sesbania sesban, Leucaena diversifolia, L. pallida* and *Chamaecytisus palmensis*) in Ethiopia, Kenya and Uganda. The recommendation domains were selected based on climatic, edaphic and topographic factors. The likelihood of adoption, within the agro-ecologically suitable areas for each species, has been defined by weighing and combining three factors: the type of land cover/land use, the human and cattle population densities.

Key words: adoption potential, multi-purpose trees, Ethiopia, Kenya, spatial distribution, Uganda

Introduction

Poverty, low agricultural productivity, widespread land degradation and hence a diminishing capacity to support the growing human and livestock population are major problems in the East African region, particularly in the densely populated highlands. In recent times, there is an increasing interest with leguminous multi-purpose tree (MPT) species due to their potential role in addressing some of these problems. Multi-purpose trees have the ability to fit into farming systems as a source of feed and forage for ruminant and non-ruminant livestock, green manure, mulch, soil conservation, medicine, fuel wood, implement and construction. The MPTs can also offer shade, shelter and can be used as wind and firebreaks while the nitrogen fixing trees contribute an appreciable amount of nitrogen to crop lands (Van Den Beldt, 1994). In addition, they may offer advantages over herbaceous species in terms of superior persistence, higher dry matter (DM) yields, better resistance to mismanagement and a capacity to retain high-quality foliage under stress conditions. They can also fit unobtrusively into the small farmer holdings, either as spaced trees within cropped land or grown along boundary lines, often as hedges. The increasing attention paid to these species can be confirmed by the number of databases and mapping systems developed to assist identifying trees species suitable to different areas (Webb *et al*., 1984; Carlowitz *et al*., 1991 and Cab International, 2000).

Five MPT species have been tested on-station and on-farm for several years in Ethiopia, Kenya and Uganda to assess their suitability. They are: *Calliandra calothyrsus* (calliandra) native to the Yucatan peninsula in Mexico, *Sesbania sesban* (sesbania), native to the east and Southern African regions, *Leucaena diversifolia and L. pallida,* natives to South America and *Chamaecytisus palmensis* (tagasaste) native to the Canary Islands (Kahsay Berhe *et al.*, 1998 and 1999; Paterson, 1995). Considering the fodder value as the pre-eminent criterion, these five MPTs are all listed among the most suitable species to the tropical farming systems (Shelton, online linkage).
Using Geographical Information Systems (GIS) tools, the objective of this paper was to analyse the likelihood of adoption for these species within their agro-ecologically suitable areas, in Ethiopia, Kenya and Uganda. Existing spatial data and Geographical Information System (GIS) technology are extremely useful in generating information that can be of support to decision makers (Diagne, 1995).
The first step of the analysis included the definition of recommendation domains based on climatic, edaphic and topographic factors. A similar approach was previously used by other authors (Booth *et*

al., 1989 and Booth, 1998) in producing mapping outputs using climatic and soil data to identify suitable areas for particular species in Africa. In this document, maps of the likelihood of adoption for the MPTs species were then produced throughout a multi-step process. The digital layers of the present land cover types, of human, cattle density values were first overlaid with the recommendation domains, and the resulting maps were finally reclassified to define different likelihood of adoption.
The mapping outputs could be useful to land use planners, extension services and NGOs as they could be a support tool in the decision process while helping in identifying priority zones where the adoption is more likely to be successful.

Materials and Methods

In the present work, GIS tools were used to query, reclassify and overlay available digital data to identify the recommendation domains of five species in terms of agro-ecological requirements and to combine this information with layers of land use, human and cattle population densities, which are believed to influence the adoption of MPTs.

The edaphic and ecological requirements for each species were derived from the research conducted at ILRI, literature, personal communications and available databases such as The Multi-purpose Tree & Shrub Database produced by the International Council for Research in Agroforestry in collaboration with the German Technical Co-operation (Carlowitz *et al.,* 1991).

The Almanac Characterization Tool (ACT) (Corbett *et al*., 1999) was used as the principal source of digital layers. The ACT includes climatic, soils, land cover and socio-economic data layers. Interpolated climatic surfaces produced from long-term weather station records are reported in the ACT with a grid resolution of three Arc-minutes (approximately 5.5 km grid cell size) (Corbett and Kruska, 1994).
Soil information was derived from the Digital Soil and Terrain Database of East Africa (SEA) produced by the Food and Agricultural Organization (FAO, 1997). The SEA, that is included in the ACT, reports soil information for the three dominant soils in the mapping units at 1 million scale.

The adoption of MPT species can be positively related to the occurrence of agricultural production systems. Incompatible land cover/land uses such as urban settlements, water bodies and industrial areas should be taken into account while identifying the likelihood of adoption of these species.
At present, remote sensing data are widely recognized as important source for land use/land cover mapping (Lillesand and Kiefer, 1994). The ACT includes land cover/land use layers generated from NOAA (National Oceanic and Atmospheric Administration) – AVHRR (Advanced Very High Resolution Radiometer) satellite data at 1 km resolution by the United States Geological Survey (USGS-EROS, 1996). These layers were used in the analysis of Kenya and Uganda. Satellite sensors employed to produce images of the earth have different spatial resolution and then different capabilities to capture digital information of the reality on the ground. For this reason, a different land cover layer (Odenyo, 1984), was used for Ethiopia, having the remote sensing (Landsat Thematic Mapper) data employed in its development higher spatial resolution than NOAA – AVHRR data. In order to define the likelihood of adoption, the present analysis also took into account the cattle and human population densities. The choice of the digital layers employed in the analysis depended on the most recent data available. For Uganda, recent data (1999) at district level were assembled to generate a layer of human and cattle population densities. Digital data on cattle and dairy population, generated at ILRI (1997 base information, unpublished) were used for Kenya while, for Ethiopia, the cattle population layer was taken from the ACT (Kruska *et al.,* 1995). The ACT represented the source of data for human population, in Kenya and Ethiopia, while for Uganda the digital layer mentioned above was used.

The identification of recommendation domains is based on the criteria through which the original data should be queried and analysed. The system developed within the GIS relies on two different types of criteria: constraints and factors. Within the analysis, constraints are those criteria that differentiate areas identified as suitable from those unsuitable under any condition. Factors are instead criteria that define areas or alternatives in terms of continuous measure of suitability. Individual factor scores may either enhance (with high score) or detract from (with low score) the overall suitability of an alternative (Eastman, 1999). In the present analysis, the edaphic and climatic requirements for each of the species considered (Table 1) were analysed as constraints through a Boolean logic and GIS operations like intersecting and overlaying. The results of this kind of analysis are layers where only the areas that match all the conditions (constraints) are defined as suitable. All the areas outside the recommendation domains were scored as not valuable for this specific technology. At this step, the analysis of the different constraints leads to a unique degree of suitability.

Table1 shows some of the edaphic and climatic requirements that were used to establish the agro-ecologically suitable areas for the five MPT species in the three countries. Rainfall, temperature and altitude intervals represent required ranges of the MPTs relatively to these parameters. Due to limitation on data availability, it was not possible to use the same parameters to assess temperature requirements for the different species. Tagasaste is mainly reported to adapt in the range of mean minimum and mean maximum temperature of –1 and 30 °C respectively, while different authors report resistance even at lower temperature (Snook, 1986; Kahsay Berhe and Tothill, 1997). The pH intervals reported in the soil reaction section take into account characteristics like performance on acid soils or tolerance to salinity. For example, a range of pH from 4.0 to 7.0 has been used for *C. calothyrsus*, which is reported to perform well in soils with acid reaction, but it is not tolerant to salinity. For *S. sesban* that grows well on a wide variety of soils, a broader range (5.0 - 9.0) was used. The species analysed show different degrees of tolerance to drought. The climatic layers have then been queried for the number of dry months. The susceptibility of calliandra to water logging and salinity was also taken into account by querying the soil layer for these characteristics and cutting off the selected mapping units.

Insert Table 1 about here.

Within the same agro-ecologically suitable area, we should expect to find different degrees of likelihood for the adoption of these MPTs in the farming systems due to other factors, e.g. human and livestock population densities. In the densely populated areas of the mountain regions, research focuses on reducing soil erosion and degradation on steep slopes using trees on contours. Where farms are too small and land pressure too great for any fallow, research focuses on improving soil fertility without interrupting the cropping cycle. Therefore, high human population pressure reflects on the need for more land to be cultivated and restriction for livestock to graze only around the homesteads, roadsides and on marginal lands. In this kind of situation, the scarcity of animal feed is considered as one of the major constraints in livestock production and therefore the MPT species, when properly managed, can alleviate and address these problems.

In this document, the earlier Boolean approach was refined by giving a score (weight) to some of the factors that can influence the adoption. What was previously represented by a single value has been disaggregated in degrees of likelihood (from none to very high likelihood of adoption of the MPTs). The agro-ecologically suitable area for each species was overlapped with the digital layers of the three factors. The layers generated were then transformed in to grids and reclassified with an internal score. Final scores range from 0 to 3, where 0 represented the lowest likelihood (none), 1 the low, 2 the high and 3 the very high likelihood. GIS tools allowed displaying, for each grid, the histograms of the number of pixels distributed in each likelihood class. The pixel is the smallest component of the mapping grid.

Digital land cover layers consist of polygons representing different features of the earth and described through a land cover classification system. The use of land cover layers should consider that the land cover classes are somehow arbitrary depending on the system employed by different developers. The reclassification made for the land cover classes took into account several considerations while those made for the human and cattle density layers were based on the identification of thresholds or ranges within the values. The ranges adopted were considered to represent significant changes in terms of likelihood of adoption. As a final step, the grids generated for each species were summed, producing a final output with 0 as minimum and 9 as maximum possible value. For mapping purposes, the final grids were again reclassified, giving to 0 the lowest value (no likelihood), the interval between 1 to 3, low likelihood, interval 4 to 6 high and interval 7 to 9 the very high likelihood. Within this analysis, the three factors were considered to equally influence the likelihood of adoption.

Land cover

Table 2 shows the score given, in terms of likelihood of adoption to each of the existing land cover classes in USGS land cover classification. Water bodies, as well as urban built-up areas, were scored as having the lowest likelihood of adoption. Despite the fact that forested areas could be suitable for MPTs, they were associated with low likelihood as it was considered prevailing the need to preserve them. The areas under savannah were weighed with a lower likelihood of adopting MPTs than areas that are already under cultivation. Due to the higher spatial resolution, the land cover layer available for Ethiopia is more detailed but similar guidelines as those described above were followed in reclassifying the land cover classes. Land use alternatives to cropping, such as the eucalyptus woodland class present in the Ethiopian land cover layer, were evaluated with low likelihood. As a rule, all the zones under cultivation were scored with the highest likelihood (both in single or mixed classes). The classes were also evaluated with regards to the characteristics of the species analysed. For example, calliandra presents a quite aggressive growth and abundant seed that indicate a high weediness potential if mismanaged and if left to colonize riverine areas where watercourses highly facilitate a rapid spread of the seeds. For this reason, the riparian woodland or bushland class, present in the Ethiopian layer, was classified as unsuitable for adoption (no likelihood).

The areas overlapping National parks and reserves were removed by overlaying and editing the digital layer of the ACT that contains this information. This was important to avoid overestimation of the land cover factor for Kenya.

Insert Table 2 about here

Human and livestock population densities

High human and livestock population densities were associated with high probability for farmers to introduce these MPTs in to the farming systems. Table 3 shows the ranges of both human and cattle density values and associated likelihood of adoption. The relevance of the adopted ranges in the present analysis has been confirmed by other studies, like Pender *et al*. (1999).

The digital layer available for Kenya included both cattle and dairy cattle density. The presence of dairy cattle was considered positively correlated with the likelihood of adoption of the MPTs as important sources of feed for high value animals. Two separate grids for the cattle and dairy cattle density were generated and reclassified using the same ranges as reported in Table 3. They were finally recombined in a final grid that sum, in each pixel, the relative importance of the two factors.

Insert Table 3 about here.

Results

Calliandra calothyrsus

The agro-ecologically suitable area for this species covers about 235,000 km^2 in the Western and South Western part of Ethiopia. In Uganda, it spans to over 165,000 km^2 avoiding the North Eastern and the South Western zones. In Kenya, it almost entirely falls in the South Western zone bordering Uganda and covers roughly 24,000 km^2. The analysis of the land cover layers shows a similar trend in the three countries with the high and very high likelihood of adoption in a large part of the three countries suggesting that, this factor could positively influence the adoption of this species. The analysis of human population density effect shows instead a more irregular pattern. In Ethiopia, a large part of the agro-ecologically suitable area shows no likelihood of adoption while higher likelihood exists in suitable areas that fall in the high-populated highlands. This factor also scores low likelihood of adoption in Uganda while in Kenya very high likelihood is dominant. In the three countries, the highest human population density values are associated with the highest cattle densities values.

Figure 1 shows the resulting grids for the three countries combining the three factors. By further overlaying this type of output, for calliandra as well as for the others species, with a layer of administrative boundaries, it is possible to target those districts where the adoption process is more likely to be successful. The mapping outputs for each country and species, analysed to calculate the areas with high and very high likelihood of adoption, are shown in table 4.

Insert Figure 1 about here.

Insert Table 4 about here.

Sesbania sesban

The total suitable area for this species covers about 346,000 km^2 in the three countries and encompasses particularly the zones from mid to high altitude and with relatively short dry periods. Due to partial overlapping of the agro-ecologically suitable areas of sesbania with calliandra, the analysis of factors shows a similar pattern. The histograms of the land cover grids confirm the positive weight of this factor in the region, being the largest percentage of the pixels with high and very high likelihood of adoption. The human population factor mainly scores, in Ethiopia, no or low likelihood of adoption with the exception of the agro-ecologically suitable area that falls in the highlands and where very high likelihood of adoption is registered. The scores of likelihood related to the human population factor in Kenya and Uganda show very high values for the areas encompassing the central part of the border between the two countries. None of the three countries shows very high likelihood of adoption with regards to cattle population and no and low likelihood classes prevail for this factor in the agro-ecologically suitable areas. The combination of the final grids (Figure 2) shows a heterogeneous situation in Ethiopia where low and high likelihood of adoption prevail.

Insert Figure 2 about here

Leucaena diversifolia

L. diversifolia was found suitable to as restricted areas as about 19,500 km^2 in Western Ethiopia and 1200 km^2 in Kenya and Uganda. For this reason, figure 3 shows the combination of the three factors exclusively for Ethiopia. The land cover factor seems favourable to the adoption, showing the grid a prevalence of pixels with very high likelihood of adoption. The human population density is instead less positive because low likelihood of adoption is mainly represented. The areas classified as dense forest in the land cover layer coincide with the lowest human density values thus displaying a good level of accuracy in the matching of the digital information. Limited areas show positive likelihood of adoption based on cattle density. In the final combination, only restricted areas score the highest value of adoption and the low value of adoption is the most represented.

Insert Figure 3 about here

Leucaena pallida

The North Eastern zones of Uganda and the central Southern areas of Kenya encompass the agro-ecologically suitable area for this species. The total surface in the three countries is about 415,000 km^2 of which, more than 60% falls within Ethiopia. The land cover factor shows high and very high likelihood of adoption in the three countries. The human population factor shows low likelihood of adoption in the three countries. The suitable areas cover wide drought prone zones with low human density values. The analysis of the cattle population density showed a similar pattern in all the countries. Very high likelihood of adoption was not evident for any of the countries with the exception of limited areas within the Ethiopian highlands.
Figure 4 shows the combination of the three factor grids within the recommendation domains in the studied countries.

Insert Figure 4 about here

Chamaecytisus palmensis (tagasaste)

This species had the largest suitable area among all other species. In Ethiopia it extends widely to about 290,000 km^2, roughly avoiding the central highlands (where waterlogged soils predominantly concentrate). In Kenya and Uganda, the suitable area is about 140,000 and 145,000 km^2, respectively. The influence of land cover factor in terms of likelihood of adoption seems to be highly positive in the three countries. Due to the width of the suitable areas, the pattern of likelihood associated with human population density shows a high variability within the countries. In Ethiopia, the classes of likelihood of adoption are equally represented throughout the agro-ecologically suitable area except the very high likelihood that covers only a restricted area. In Uganda, low likelihood of adoption for the human population factor prevails while in Kenya, the largest part of the suitable area scores no likelihood of adoption.

As mentioned in the analysis of the previous species, the Ethiopian highlands score the highest values both for human and cattle population factors. In Uganda, the largest part of the area shows the lowest likelihood of adoption for the cattle density factor. The final grids (Figure 5) show the pattern of likelihood in the three countries. In Ethiopia, several zones in the northern highlands as well as a large part in the South West of Uganda have high likelihood of adoption. Despite the width of the suitable area in Kenya, a major part of the area scores low likelihood of adoption and therefore low probability of success for adoption.

Insert Figure 5 about here

Discussion

Calliandra calothyrsus

The analysis of the different factors showed that few zones in Ethiopia could be effectively targeted for diffusion of this species. As shown in table 4 about 30% of the agro-ecologically suitable area in this country scored high to very high likelihood of adoption. Within the large agro-ecologically suitable area, low likelihood of adoption was indeed the most represented value based on the combination of the three factors. This means that the recommendation domains encompass areas not favourable with respect to the socio-economic factors that can influence adoption. The opposite situation was recorded for Kenya where, despite limited agro-ecologically suitable area, high and very high likelihood of adoption prevailed accounting for 80% of the total suitable area (Table 4). This species could be particularly promising in Uganda where, not only it covers a large suitable area but also shows the highest values of likelihood (54%) based on all three factors.

Sesbania sesban

This species is native to the Eastern and Southern African regions and is adapted to waterlogged and cool temperature areas that are free from frost and salinity (Steinmüller, 1995*). Sesbania* species are a potential source of high quality forage with leaves and tender stems that are readily eaten by large and small ruminants. The analysis of the pattern of adoption for this species, in Ethiopia, indicates that large areas (52%) of the recommendation domains have farming systems where this species scored high and very high likelihood of adoption. In Ethiopia, the extension services of the Ministry of Agriculture present in each district and the important network of small nursery centres, is highly encouraging for the further diffusion of sesbania particularly in Southern regions. A similar favourable situation was encountered in East Uganda and West Kenya.

Leucaena diversifolia and *L. pallida*

Previous studies (Kahsay Berhe and Tothill, 1995) identified the superior performance of these species as highly productive and protein rich fodder producers for use in the typical crop-livestock smallholder farms of the tropical highlands of Ethiopia. Even though the suitable area for *L. diversifolia* is quite limited, it is worthwhile considering the introduction, as the number of MPT species that grow well on cool temperatures and acid soils are limited. About 40% of the suitable area scores high and very high likelihood of adoption (Table 4). The present analysis highlighted the South Western zones of

Ethiopia for having the optimum conditions for the adoption of both *L. diversifolia* and *L. pallida*. The latter species showed also high likelihood of adoption in several areas in Eastern Ethiopia. Despite the fact that the suitable area covers a large portion of the country, only restricted zones (26%) scored high and very high likelihood of adoption. Similarly, very few zones in Kenya and Uganda are reported to have the highest values of likelihood of adoption for this species. Low likelihood was the most represented in these countries.

Chamaecytisus palmensis

Since its introduction to Ethiopia by the Ministry of Agriculture (MoA) in 1984, tagasaste is widespread in the country and the MoA's Fourth Livestock Project has achieved considerable success with general recommendations for planting this species on well-drained soils. Currently, it is believed that over 100,000 farmers are growing this species in the highlands in almost treeless areas at altitudes up to 3500 m (Robertson, 1998). Tagasaste could produce a supply of high quality supplementary feed, although any decision to incorporate it in a farming system must take into account the difficulty of establishment and management of the plant, and how it may best be utilized. In Kenya (Paterson *et al*., 1998) reported that no work has been done to define suitable species for altitudes higher than 2000 m and hence the current information could help to fill the gap of shortage of species adapted to higher altitudes. Favourable situations in terms of likelihood of adoption were recorded for the highlands in Northern Ethiopia and in the South West highlands of Uganda. Some of the areas with the highest likelihood of adoption in Ethiopia refer to coffee based farming systems. This production systems have already been targeted for introduction of agro-forestry systems and MPTs to tackle some of the farmers' needs such as conservation of moisture, shade and soil fertility, the improvement of coffee production and quality and the provision of fodder and fuel wood as well as the need to arrest land degradation. This species seems to be quite promising for Ethiopia, where over 50% of the very large suitable area scores the highest values of adoption. Similarly, 43 and 48% of the suitable areas for Kenya and Uganda respectively, had high to very high likelihood of adoption.

Conclusion

The analysis of likelihood of adoption of these Multi-purpose Trees in the farming systems of Ethiopia, Kenya and Uganda, was performed through a multi-criteria approach using a Geographical Information System. The introduction into farming systems of a new technology should consider the capability and willingness of the farmers in adopting it. Despite the tremendous advantages of the use of MPT species, the adoption rate can be lower than expected due to constraints like the increase in labour requirement, difficulty of management or the presence of more economic alternatives. Furthermore, MPT species suitable to smallholder farming systems in the analysed countries, should guarantee good performance and quick growth.

The spatial stratification coupled with appropriate local knowledge and interpretation, can provide relatively low-cost insights into development constraints and opportunities, their significance and the complexity to be addressed. Two different kind of analysis of the spatial information were applied in the present document in a complementary way. The Boolean approach allowed identifying the recommendation domains of the species in terms of agro-ecological requirements by GIS operation like querying and overlaying. Because of the approach used, the overall suitable areas may appear more restricted than they can be in reality. The ranges of the parameters used to analyse the databases should then be validated with a larger number of on-farm testing under different conditions. The Boolean approach leads to a single degree of suitability where all the imposed conditions are met. This single value of suitability was then disaggregated through the attribution of degrees of likelihood. In this document, the existing land cover, the human and cattle population densities were analysed as they are assumed to influence the adoption process. These factors were weighted and associated to classes of likelihood of adoption (from none to very high) for each species. The coupling of the biophysical requirements with other factors helped in the spatial definition of the target areas where the MPTs technology is more likely to be adopted. This type of result can be useful in identifying priority zones where the adoption process could be more successful.

The overall accuracy of the outputs depends on the spatial resolution of the digital layers that have been used. Available climatic surfaces interpolated from long-term weather station records were utilised. The fitting programs used to interpolate the surfaces determines the optimal trade-off between goodness of fit and surface smoothing and allows for weighing each weather station. The analysis of the soil information took into account the attributes of the dominant soil and associated soils in the mapping units. Ranges of human and cattle population density should be calibrated to test their reliability in defining changes in the adoption process. The resulting spatial domains could be further refined adding updated and higher resolution information, local knowledge and more socio-economic layers. For example, the capillarity of the extension service, the presence of seed and seedling distribution centres and the land tenure pattern are other factors to consider in the evaluation of the probability of adoption and success of this strategy. A GIS-based analysis of the road systems could give further information with respect to the adoption of the MPTs particularly where livestock enterprises like dairy and fattening programmes are predominant. MPTs are valuable fodder suppliers for such valuable animals and indirect evidence for their adoption relies on the presence of road facilities for the market of a perishable good like milk. High human and cattle population densities are usually associated to higher soil erosion rates. Hence, areas with high human and cattle population densities and steep slopes can be related to higher likelihood of adoption. Where livestock are tethered and cut and carry systems are allowed, MPTs can easily be grown on farmlands and farm boundaries. The availability of digital databases on these and other factors could therefore help refining the likelihood of adoption and targeting interventions.

Within the same recommendation domain, the scoring of socio-economic factors leads to a high heterogeneity in the possible scenario of adoption. Even if the suitable areas for some of the species partially overlap, they cover a large range of agro-climatic conditions giving a wide base in the choice of the species to be adopted in a certain location. The current information could be useful to target not only the areas where the species could have good performances but also where the farmers are more likely to adopt the MPTs in the production systems.

NOTE

1. * ILRI Paper no. 00004

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Table 1. Edaphic and climatic requirements used for the recommendation domains of the MPT species.

Species	Climatic and edaphic conditions	Source of information
	Rainfall (mm)	
C. calothyrsus	1000-4000	Macqueen, 1993
S. sesban	500-2000	Heering, 1995
L. diversifolia	1500-3500	Hughes, 1988
L. pallida	500-1500	Hughes, 1988
C. palmensis	350-1600	Davies, 1987
	Temperature	
C. calothyrsus	20-28 ^{o}C [1]	Macqueen, 1993
S. sesban	5-30^{o}C [2]	Gutteridge and Rekib, 1995; Steinmüller, 1995
L. diversifolia	>1^{o}C(absolute min.)	Williams, 1987
L. pallida	>1^{o}C(absolute min.)	Williams, 1987
C. palmensis	- 9 to 30^{o}C [2]	Snook, 1986; Kahsay Berhe and Tothill, 1997
	Altitude (m)	
C. calothyrsus	0-1900	Carlowitz *et al.*, 1991; Kahsay Berhe and Tothill, 1995; FACT Net, 1999; Macqueen, 1993
S. sesban	0-2300	Heering, 1995
L. diversifolia	700-2500	Gutteridge, pers. com.; Shelton *et al.*, 1995
L. pallida	700-2000	Gutteridge, pers. com.; Shelton *et al.*, 1995
C. palmensis	500-3500	Robertson, 1998
	Soil reaction	
C. calothyrsus	4.0-7.0	Palmer *et al.*, 1995
S. sesban	5.0-9.0	Ghai *et al.*, 1985
L. diversifolia	5.0-7.5	Gutteridge, pers. com.; Hutton, 1984
L. pallida	4.5-7.5	Gutteridge, pers. com.; Hutton, 1984
C. palmensis	5.0-7.0	Davies, 1987; Kahsay Berhe and Tothill, 1997
	Other characteristics	
S. sesban	Drought tolerant (up to 6 months) Water logging tolerant	Evans and Rotar, 1987
L. diversifolia	Drought tolerant (up to 4 months)	Hughes, 1988
L. pallida	Drought tolerant (up to 7 months)	Hughes, 1993
C. palmensis	Susceptible to waterlogged and saline soils	Davies, 1987; Dann and Trimmer, 1986

1 Annual mean temperature in the range
2 Annual mean minimum and annual mean maximum temperatures in the range

Table 2. Land cover classes of the USGS-EROS land cover classification and corresponding likelihood of adoption for the MPTs

Land Cover Class	Likelihood of adoption (score)
Barren or Sparsely Vegetated; Water Bodies; Urban Built-up areas	None (0)
Broadleaf Deciduous Forest; Evergreen Broadleaf Forest	Low (1)
Grassland; Savannah; Shrub-land	High (2)
Cropland/Grassland Mosaic; Cropland/Woodland Mosaic; Dry-land Cropland and Pasture	Very high (3)

Table 3. Ranges of human and cattle population densities and corresponding likelihood of adoption scores for the MPTs

Ranges of human population Density /km^2	Likelihood of adoption (score)	Ranges of cattle population Density /km^2
0-40	No (0)	0-50
40-90	Low (1)	50-100
90-200	High (2)	100-250
>200	Very high (3)	>250

Table 4. Surfaces (km^2) by country of the zones with combined values of high and very high likelihood (percentages over the entire suitable areas in parentheses).

	Ethiopia	Kenya	Uganda
Calliandra calothyrsus	70777 (30%)	19180 (80%)	88750 (54%)
Sesbania sesban	106000 (52%)	22300 (32%)	33000 (36%)
Leucaena diversifolia	8000 (41%)	***	***
Leucaena pallida	75000 (26%)	20500 (33%)	9500 (19%)
Chamecytisus palmensis	170000 (5%)	60000 (43%)	70000 (48%)

Figure 1. Recommendation domains and likelihood of adoption for *Calliandra calothyrsus*

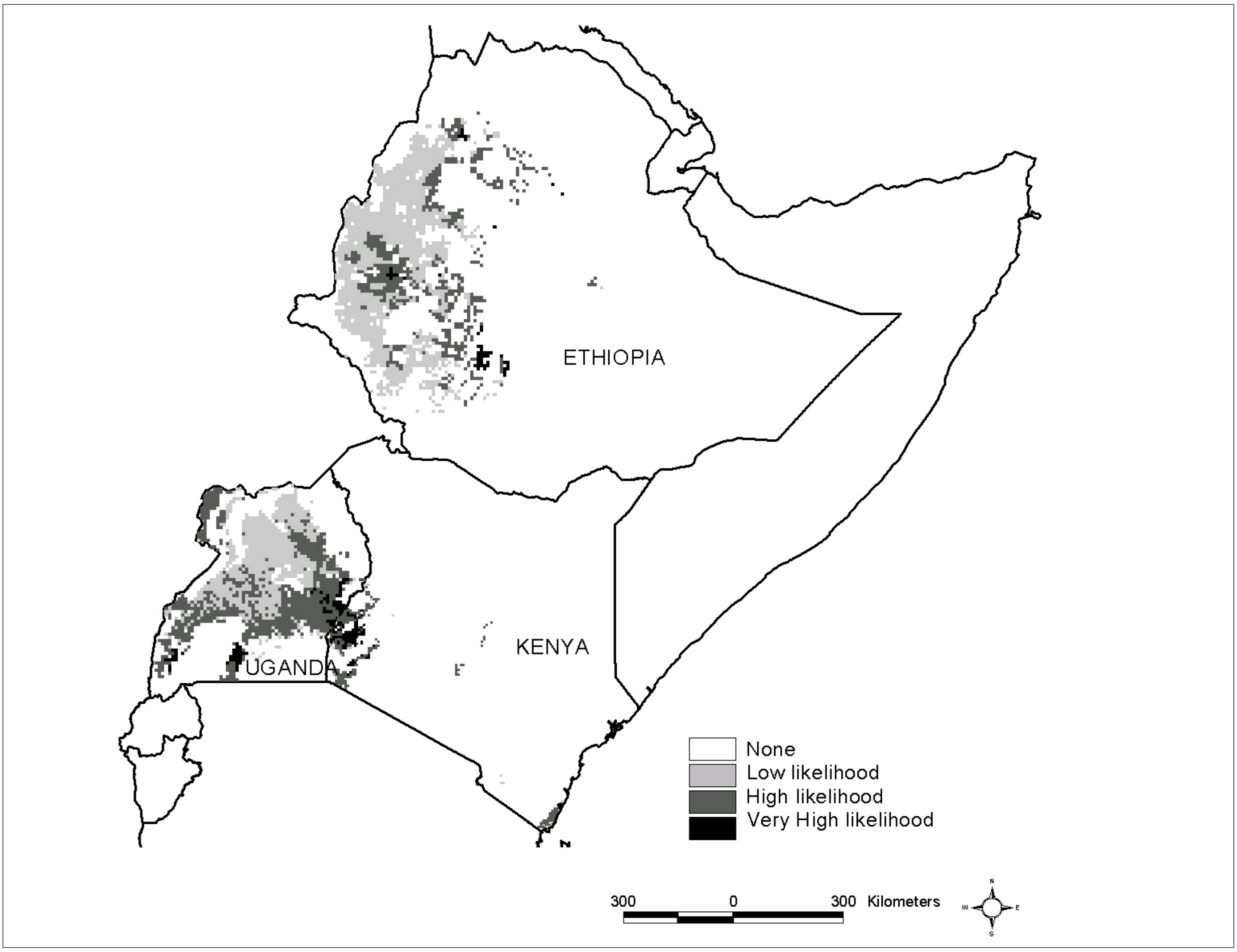

Figure 2. Recommendation domains and likelihood of adoption for *S. sesban*

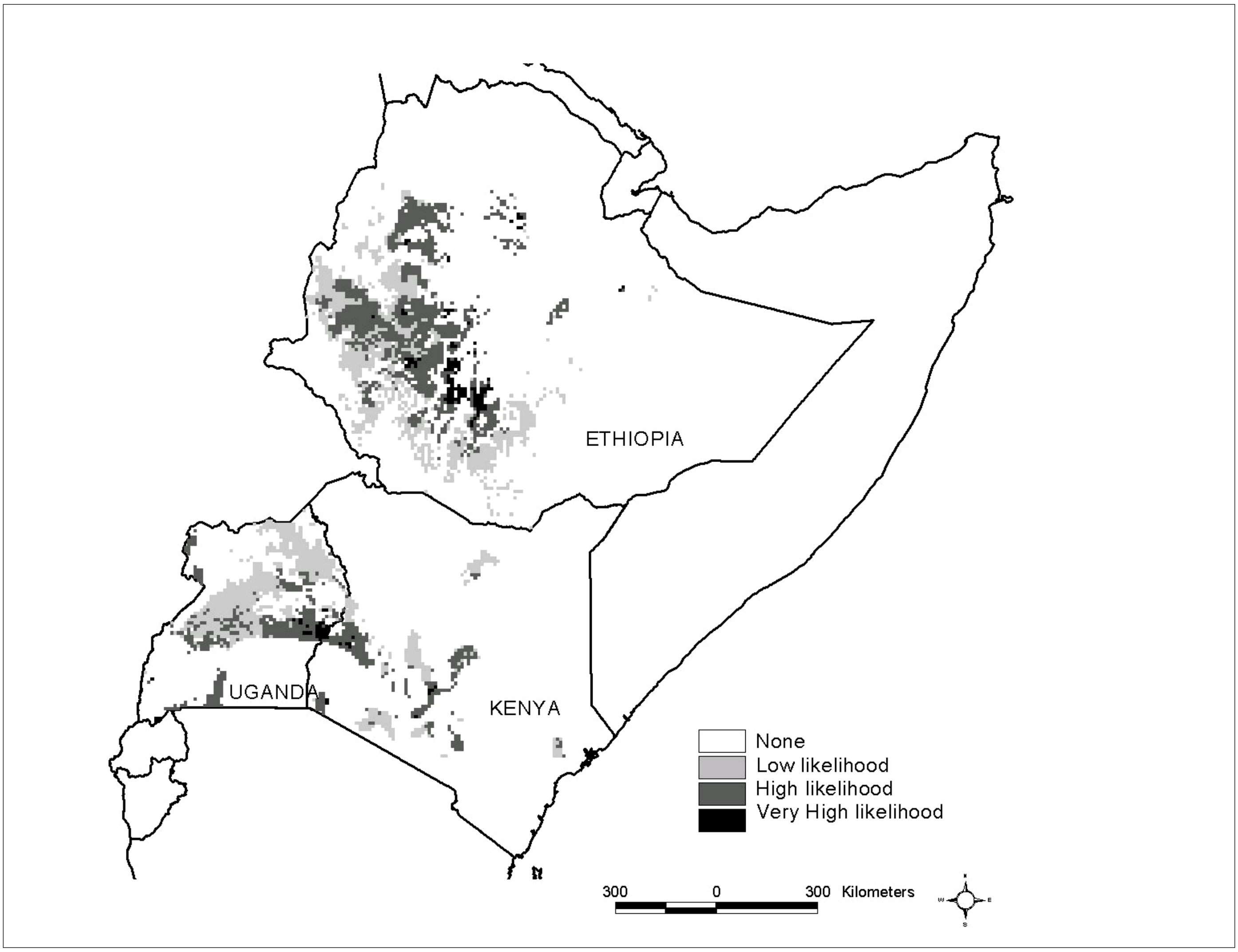

Figure 3. Recommendation domains and likelihood of adoption for *L. diversifolia*

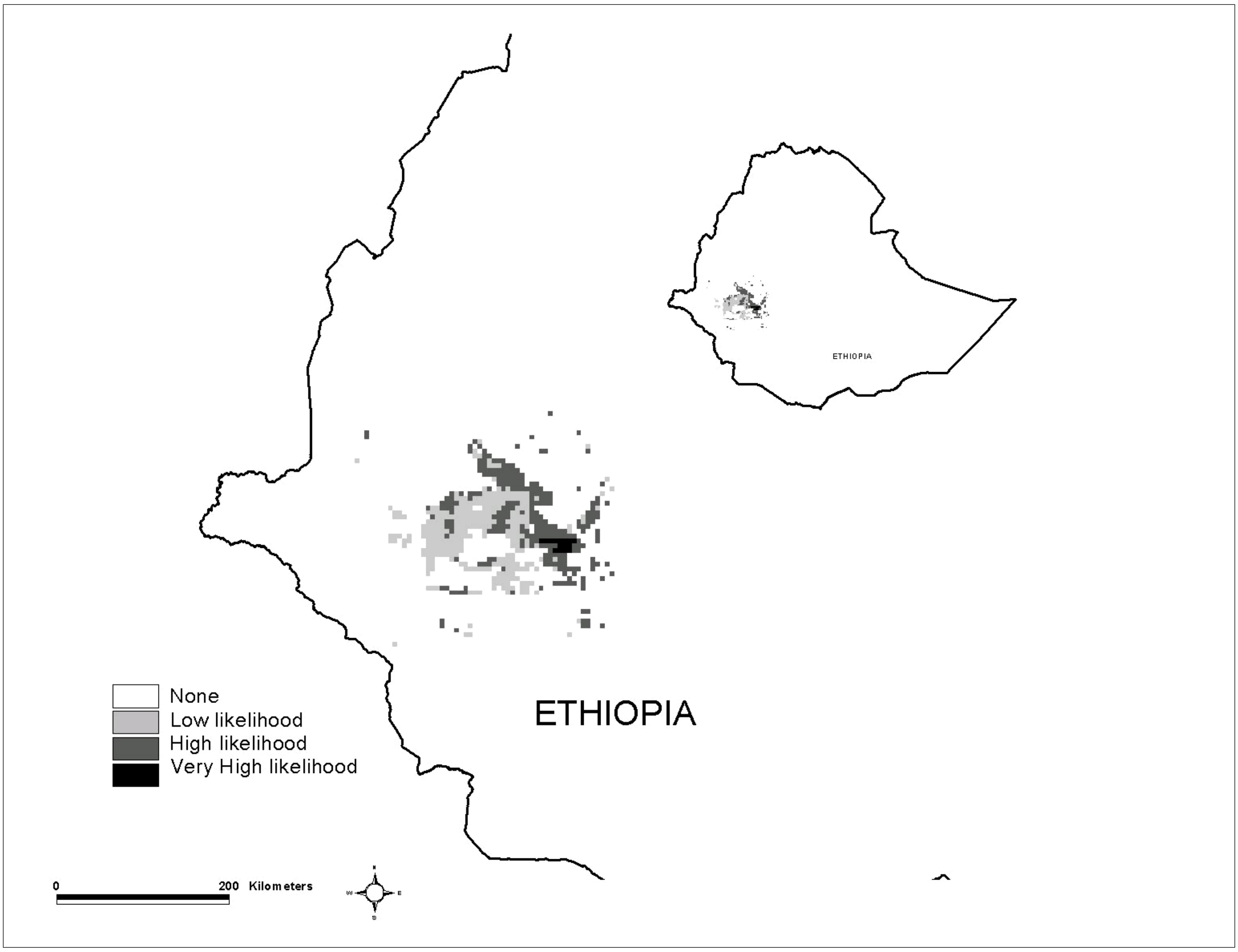

Figure 4. Recommendation domains and likelihood of adoption for *L. pallida*

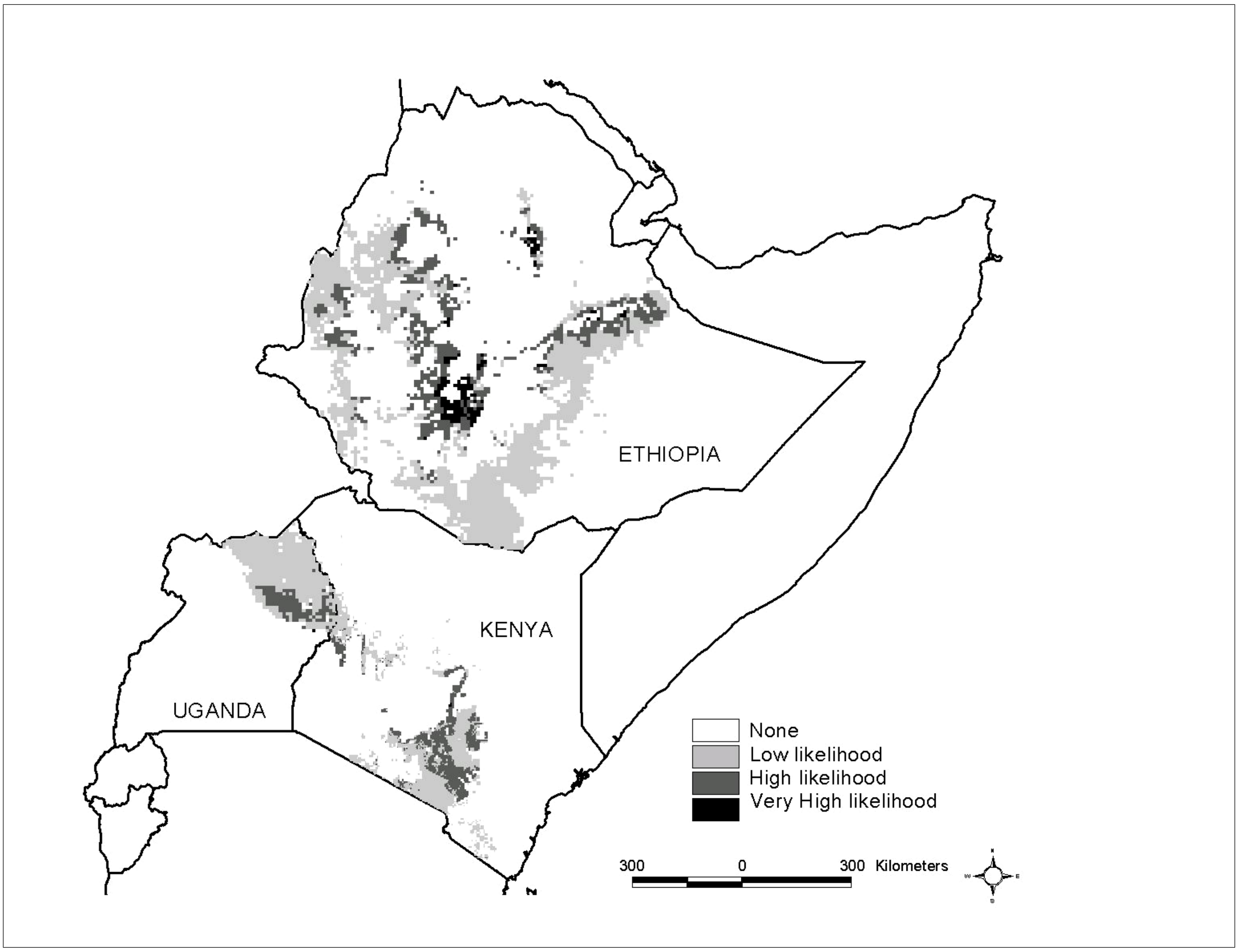

Figure 5. Recommendation domains and likelihood of adoption for *C. palmensis* suitable area