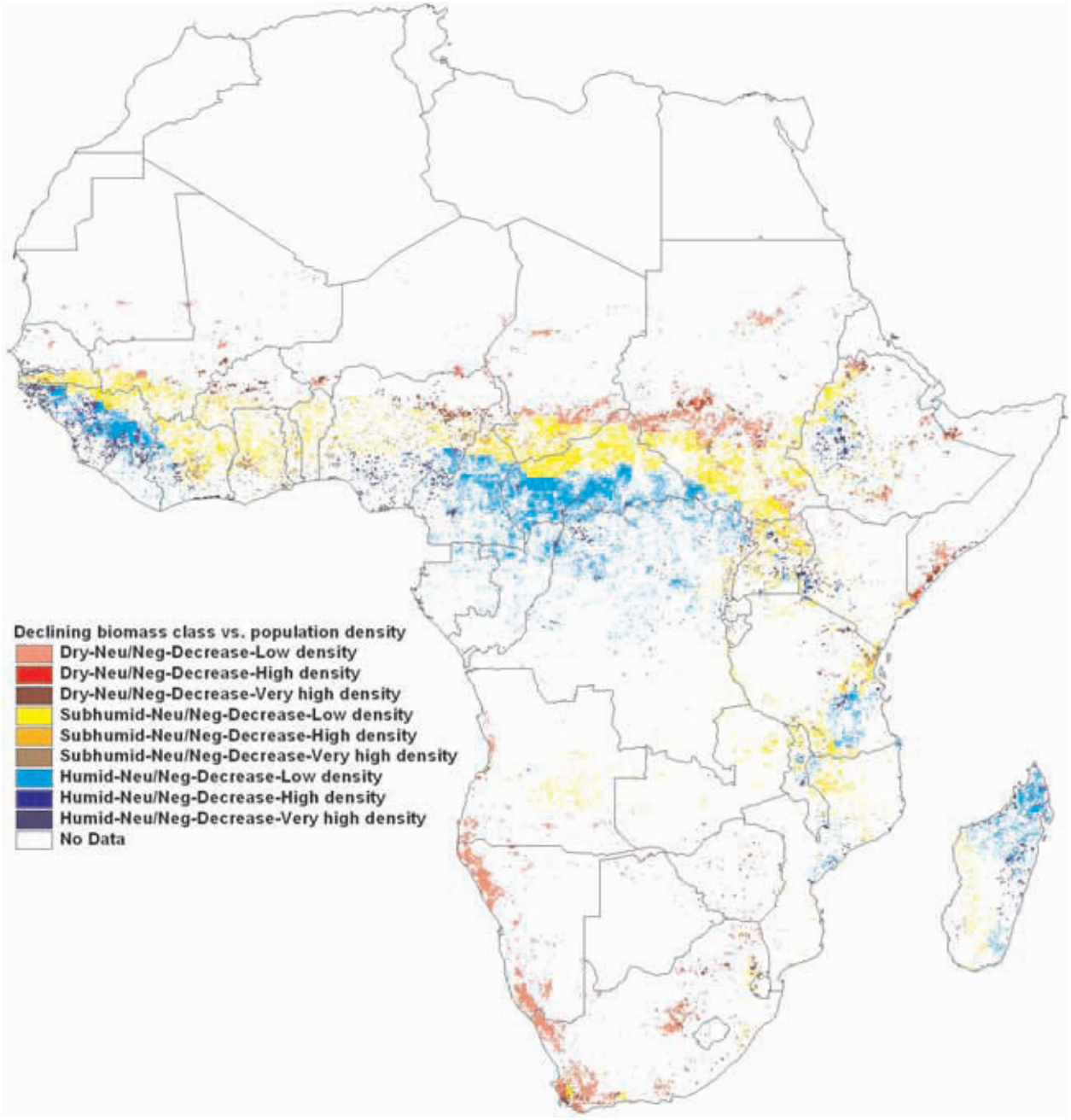
such measures are not economically sustainable, the aim might have to be to reduce the pressure on the land by offering alternative ways out of poverty.



Map 7. Green biomass decline in different climate zones that is not attributable to rainfall decline- (neu/neg Table 7) in relation to population density showing most of the declining zones to be with relatively low population density.

5.2 Terrain and soil constraints

In a next step, sub-Saharan Africa was differentiated according to the topographic and soil based suitability of the land for agriculture using FAO and USGS databases. Topographic SRTM (Shuttle Radar Topography Mission) elevation data with a pixel resolution of 1 km derived from USGS (2004) is shown in Map 8a. Pixels with elevation > 3500 m a.s.l or surface slope > 25° are considered not suitable for agriculture (see Sheng, 1990), and are not considered prime subject for further research. The bad terrain (yellow) for agriculture will require special precautions and cultivation techniques to prevent rapid degradation. The extent of such land in sub-Saharan Africa is rather limited. The remaining part of sub-Saharan Africa is considered good agricultural land (blue).

Good: 0° ≤ slope ≤ 15° and elevation ≤ 3500 m a.s.l (green)

Bad: 15° < slope ≤ 25° and elevation ≤ 3500 m a.s.l (yellow)

Unsuitable: slope > 25° or elevation > 3500 m a.s.l (red)

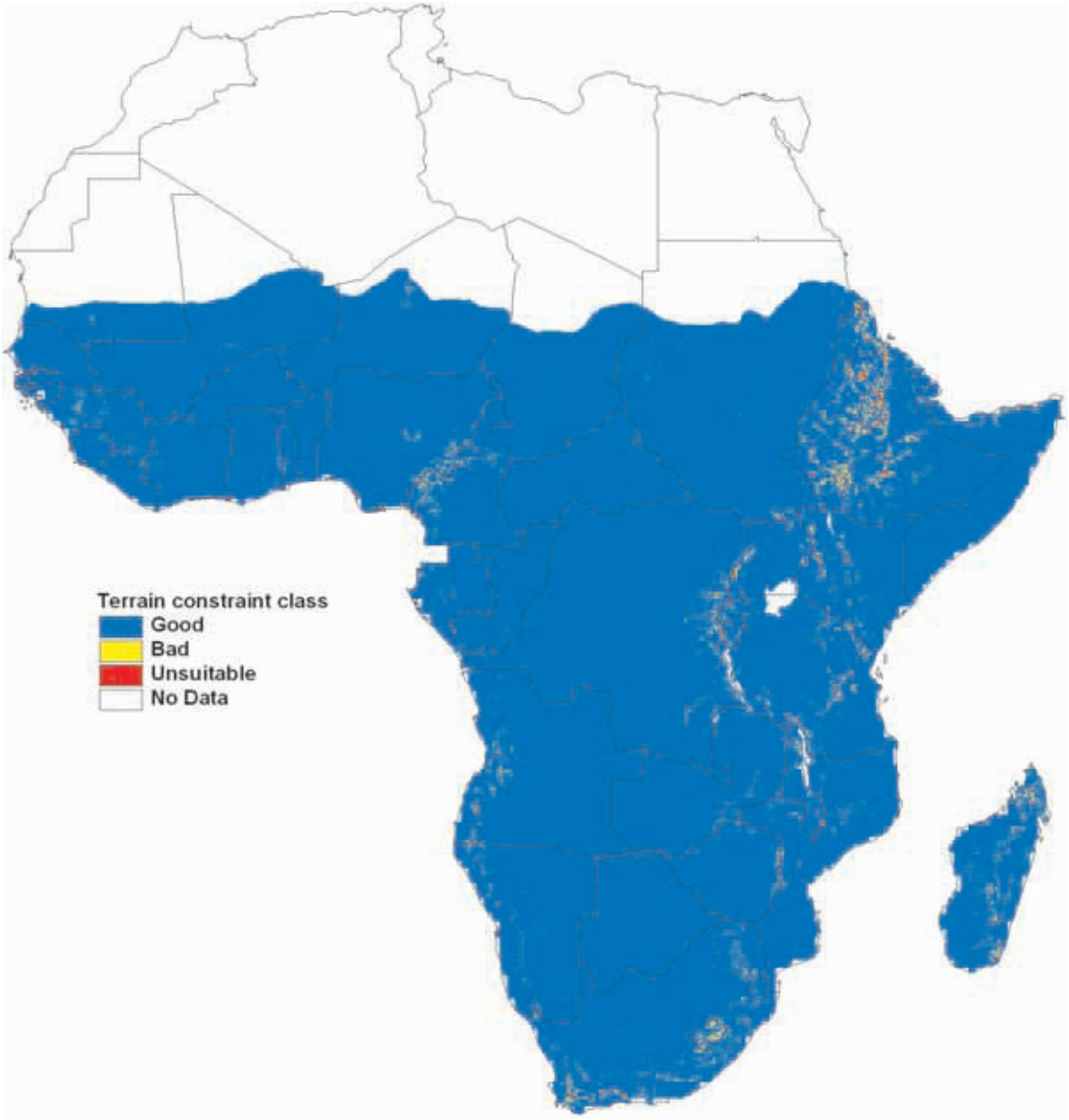
Similarly, soil constraint classes were derived from the FAO classification of soil constraints (Fisher et al., 2002) by aggregation as follows:

Good: FAO class 1 or 2 (blue)

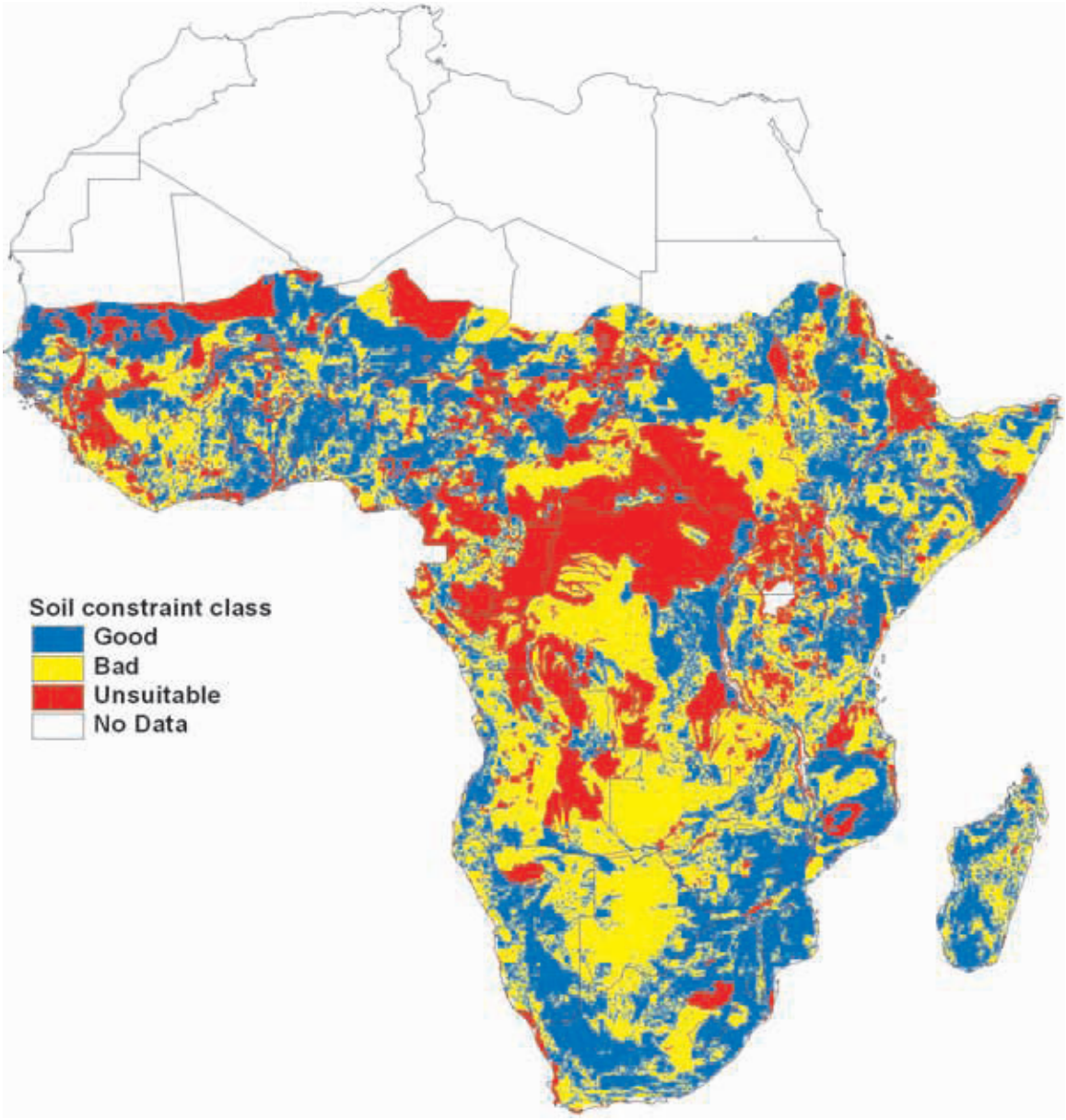
Bad: FAO class 3 or 4 (yellow)

Unsuitable: FAO Class 5, or 6, or 7, or 8 (red)

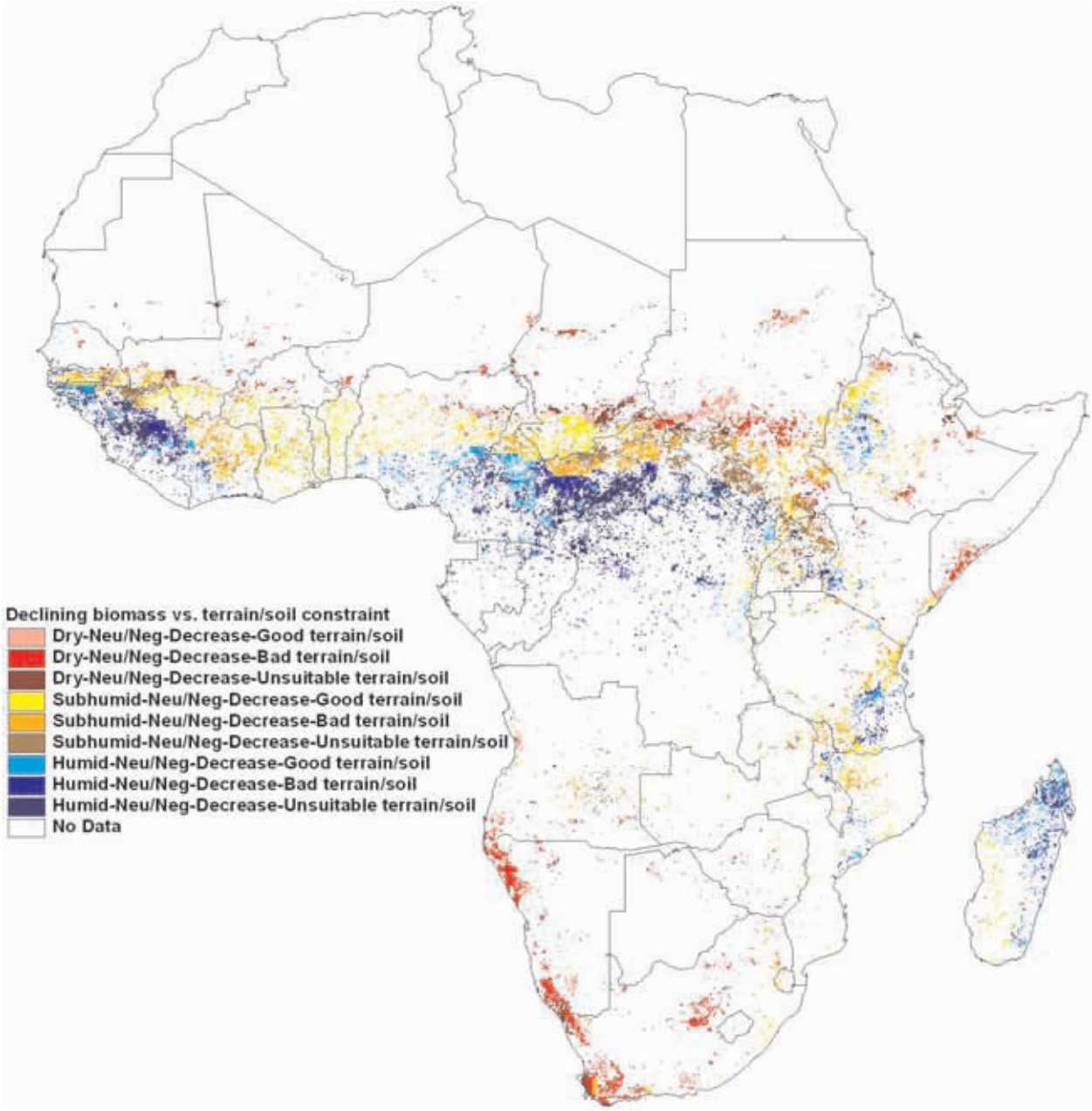
which are shown in Map 8b. Pixels in the degraded areas with very severe soil constraints (Unsuitable) include uncultivable land due to such problems as high salinity or laterite crusts and require little research attention, as investments in these lands offer little in return. Even for the regions with inherently bad soils, the economics of soil improvement may not always be favourable.



Map 8a. Terrain constraints with respect to agriculture production.



Map 8b. Soil constraints with respect to agriculture.



Map 9. Human-induced green biomass decline on land with different soil/terrain constraints.

The human-induced green biomass decline area of Map 6 can thus be redrawn by classifying the areas according to terrain and soil suitability for agriculture as shown in Map 8a,b which renders Map 9. Those areas that are unsuitable for agriculture due to topographical or soil constraints comprise about 0.68 million of the 2.13 million km^2 that were considered subject to degradation and most of it lays in the regions with relatively low population density, particularly in the sub-humid and humid regions (Table 9). Such areas, if no longer under protective vegetation, should be re-vegetated in order to restore ecosystem services. Erosion from such regions can cause damage to reservoirs and agricultural land downstream.

Table 9 Area (km²) of terrain and soil constraint classes calculated for each degradation class.

Degradation class	*Total area (km²)*	*Terrain constraint**			*Soil constraint***		
		Good	*Bad*	*Unsuitable*	*Good*	*Bad*	*Unsuitable*
Dry-Neutral/Negative-Decrease - Low density	*450689*	442751	5760	2178	177084	194302	79291
Dry-Neutral/Negative -Decrease - High density	*44794*	43899	702	194	22397	16190	6207
Dry-Neutral/Negative -Decrease - Very high density	*61492*	59968	1210	315	28157	26693	6655
Subhumid-Neutral/Negative -Decrease - Low density	*685247*	674817	7611	2819	202373	269249	213638
Subhumid-Neutral/Negative -Decrease - High density	*106879*	104387	1597	895	44092	38405	24382
Subhumid-Neutral/Negative -Decrease - Very high density	*105016*	101059	2747	1210	47674	35973	21381
Humid-Neutral/Negative -Decrease - Low density	*541124*	529218	9983	1924	113982	160833	266309
Humid-Neutral/Negative -Decrease - High density	*60669*	58685	1283	702	16129	19203	25350
Humid-Neutral/Negative -Decrease - Very high density	*76738*	74113	2239	387	32767	21756	22204
Total	*2132649*	*2088896*	*33130*	*10624*	*684654*	*782604*	*665415*

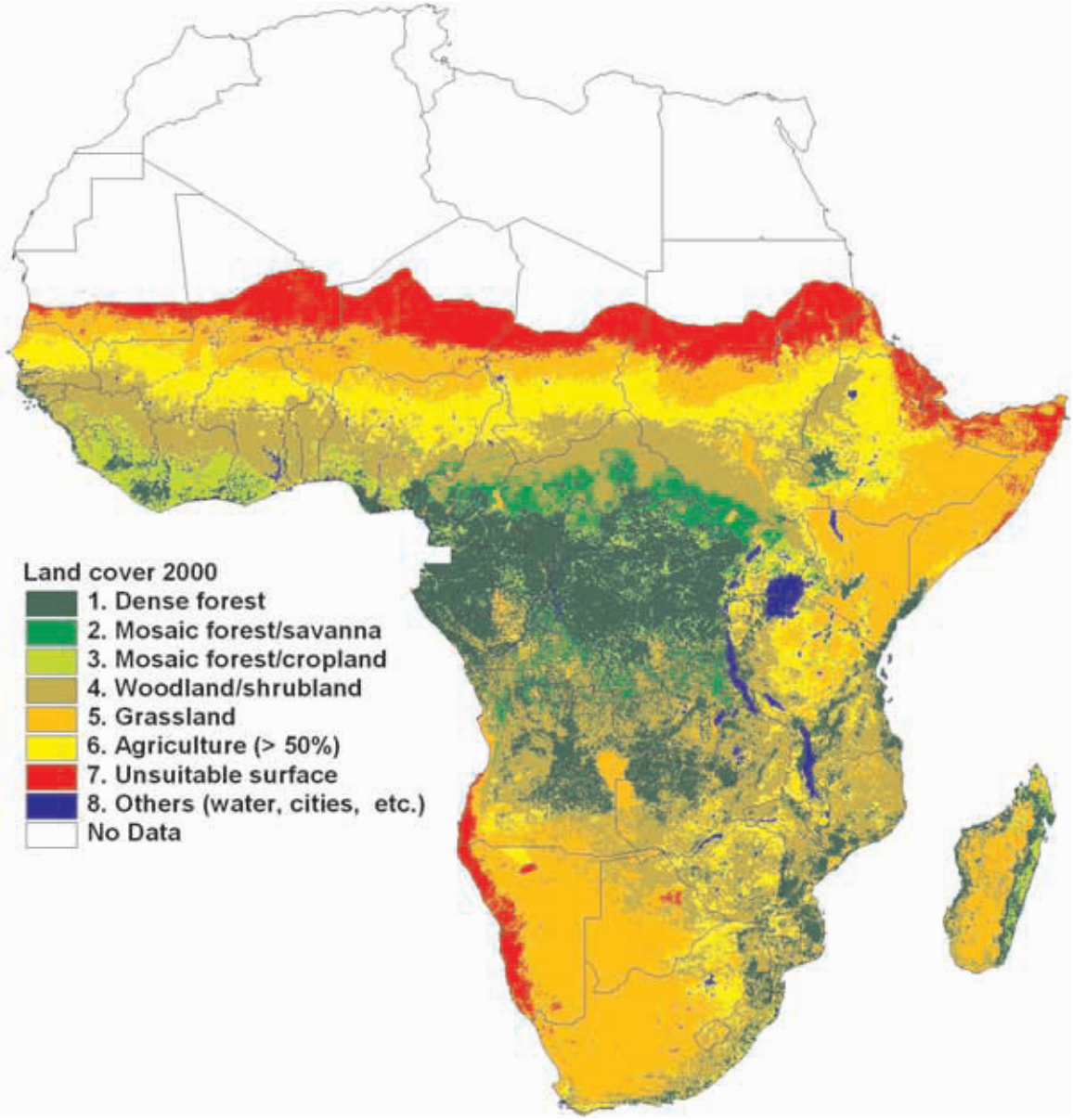
Note: * Terrain constraint classes with respect to agricultural production:
Good: 0° ≤ slope ≤ 15° and elevation ≤ 3500 m a.s.l
Bad: 15° < slope ≤ 25° and elevation ≤ 3500 m a.s.l
Unsuitable: slope > 25° or elevation > 3500 m a.s.l (eliminated in this study)
** Soil constraint classes were regrouped from FAO's classes of all soil constraints:
Good: Class 1 or 2 in FAO's classification
Bad: Class 3 or 4 in FAO's classification
Unsuitable: Class 5, or 6, or 7, or 8 in FAO's classification (eliminated in this study)

From Table 9 it is clear that degrading land unsuitable for agriculture is largely due to unsuitable soils, as the extent of land with unsuitable topography constraints is negligible. The remaining 1.45 million km^2 region with vegetation decline is found on potentially cultivable land and covers a band that extends from West Africa to Ethiopia. Some of these regions are considered the breadbaskets of Africa. Moreover, over half of this degrading (potentially) arable region is on poor quality soils. Economic returns on research investments may be more difficult to achieve in this region. The question to answer now is: what are the degrading areas actually being used for?

5.3 Land use and land cover

In order to obtain a better insight into where exactly this degradation is occurring, the entire land degradation map was cross referenced with the land use/land cover map of GLC2000. This allows differentiation of the degradation area according to land use type. Actual land use and land cover for the year 2000 was extracted from the GLC2000 data (Mayaux et al., 2004), and is shown as Map 10. It shows 8 major classes, two of which cover agriculture (3 and 6) and one pastoralism (5). This dataset is developed by the Joint Research Center (JRC) of the European Commission (EC) in partnership with more than 30 institutions around the world, using Satellite Pour l'Observation de la Terre (SPOT) VEGETATION 1-km satellite data. The quality of the map was verified using different approaches and based on data from different sources such as ground observations, national forest statistics, previous land cover maps, and high resolution satellite imagery (Achard et al., 2001; Bartalev et al., 2003; Tateishi, 2002; Cihlar et al., 2003; Fritz et al., 2003; Mayaux et al., 2004). Its quality has also been compared with other global land cover maps from different sources and employing different methods (e.g. Giri et al., 2005).

Superimposing Map 10 on Map 9 allows the development of Map 11 in which the areas with vegetation decline are categorized as suitable for agriculture and actually cultivated (brown) or not cultivated (blue). The non-cultivated areas are predominantly in grasslands and mosaic/forests. Also indicated are regions that are considered unsuitable for agriculture but are, in fact, being cultivated (red). The latter are found, for instance, on the eastern borders Sierra Leone and Liberia as well as in Uganda. Cultivating such marginal areas is likely to do more harm to the environment than it profits the farmers, and such areas should probably be rehabilitated to their natural condition as soon as possible.



Map 10. Major land-cover classes in 2000 extracted from GLC2000 data (Mayaux et al., 2004).

The statistical details of the degrading region by land-cover/use, as summarized in Map 11, are shown in Table 10. In total, about 9.4 % of the SSA region or 2.13 million km^2 is suffering from significant biomass decline. Out of the 2.13 million km^2 suffering from significant vegetation decline (Table 10), 0.68 million km^2 are not suitable for agriculture of which 80 thousand km^2 are actually being farmed and probably should not be. Means should be found to offer alternatives to these farmers so that land can be restored over time. In the dry areas, this is agricultural land whereas in the more humid regions these are the forest-cropland mosaics. Most probably these areas should be turned into exclusion zones or actively restored to their native vegetation. Of the remaining 1.45

million km^2 that are in decline but suitable for cultivation, 0.4 million km^2 are actually farmed (agriculture and forest/cropland) and are likely over-exploited or poorly managed. The area is equally divided between land with good and bad soils, except for the humid forest/cropland zone, where the bad soil/terrain areas appear to be more vulnerable. These agricultural regions require considerable research efforts in order to identify the immediate and proximate causes for their decline and to develop more sustainable farming practises.

As is seen in Table 10, a quarter million km^2 of the area under grassland, largely in the dry areas, shows a decline in vegetation, likely due to over-grazing. Of the 5.5 million km^2 of grassland in SSA, this quarter million km^2 constitutes only 5%, three-quarter of which (195 thousand km^2) are found in the dry areas where they may be affected by livestock grazing. Not surprisingly, the woodland/shrublands are most in decline in the sub-humid tropics where they are predominant, whereas the forest/savanna and dense forests are threatened in the humid areas. As much as 16% of the woodland/shrubland is in decline, probably reflecting encroachment by farmers on these natural habitats. For the expansive, more densely forested regions, the degrading area amounts to 10% of the region, most of which is unsuitable for agriculture. This may be the region of most intensive deforestation.