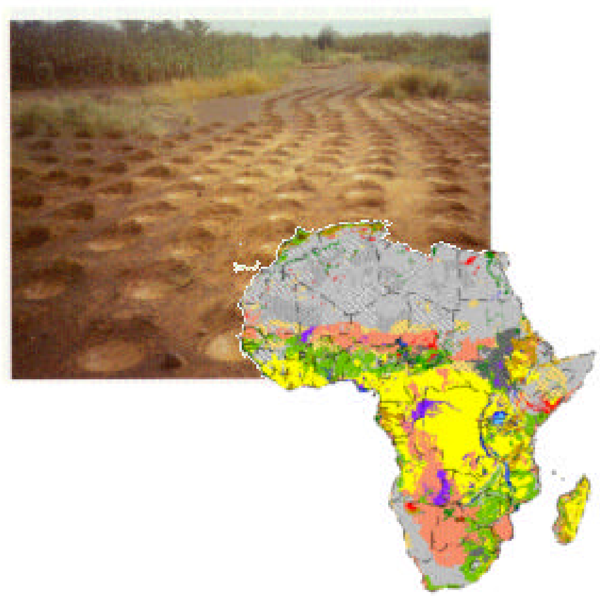
Mapping the Range of Proven Soil Management Practices in Africa

Using Digital Maps and Case Studies

by Peter H. Freeman
Development Ecology Information Service



Based on a report prepared for USAID using DEVECOL/Africa digital information resources. DEVECOL/Africa is an information resource under preparation by Development Ecology Information Service with support from USAID's Africa Bureau and Bureau for Humanitarian Relief. DEVECOL/Africa will be installed in the Food Security Resource Center of the Food Aid Management Consortium and will be distributed as a CD-ROM in 2000.

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Abstract

Soil, terrain and climate factors related to the outcomes of soil and water conservation practices in Sahelian Africa were examined using GIS programs, digital maps, and case studies assembled in a single information resource. Documented experiences in soil and water conservation in Niger and Burkina Faso were examined against a backdrop of these maps, specifically base maps derived from the Digital Chart of the World, the FAO/UNESCO Digital Soil Map of the World, and the FAO Agroecological Zonation Map (length of growing period zones). Use of GIS programs to display the recently digitized maps makes it feasible to use analytical procedures that would be impractical using the same materials in paper format. The analyses helped identify at a reconnaissance level the potential geographic range of one of the proven water harvesting techniques now being adopted spontaneously on degraded upland soils in Burkina Faso and Niger.

Effective soil conservation and restoration practices

In the drier regions of Africa, many externally funded projects were launched in the late 1970's and 1980's to deal with the environmental degradation triggered by drought and the extension of crop land onto areas of fragile soils. Outside influences or "change agents" combined with material support(food, tools, etc.) served to stimulate adoption and spread of practices.

Now many sites in Africa where soil conservation or restoration practices have been proven effective, in both research and actual practice, have been identified and documented. Some practices, such as *demi-lunes*, bunds, and planting pits (*zai* in Burkina Faso or *tassa* in Niger), have yielded impressive results in terms of increased crop production on degraded or unproductive land and are spreading spontaneously or with technical assistance.

This paper examines several practices introduced into degraded uplands, and the potential geographic range of those that have proven effective in restoring soil productivity. The purpose of the exercise was to inform strategic planning within USAID's Africa Bureau aimed at finding ways to assess the ultimate range and the impact of such practices, eventually leading to appropriately designed assistance.

How can the diffusion of soil and water conservation practices be assisted?

Case studies, many published in the last ten years or so[1], document the successes or failures of soil conservation in different parts of Africa. They reveal the myriad factors and influences that come into play in the eventual adoption and spread of different techniques. They provide the human and socio-economic context as well as environmental backdrop for considering the extension of a particular technique, such as a *demi-lune*, a stone bund, a terrace or a combination of techniques. Usually undertaken to inform policies and strategies, these studies have not been examined on a regional or continental scale against backdrop of soils and climate information and as a consequence do not attempt to identify other areas where practices might be applied. Rather, they focus attention on various conditions and factors that contribute to a practice's success or failure, without reference to their potential geographic range.

Among the many factors influencing the choice and outcome of soil and water management practices, physical environmental conditions are paramount, i.e. climate, terrain features(if hilly, flat, subject to flooding etc.), and type and status of soils. The farmer must work directly with physical environmental resources – the climate and soils – of his land, and in management of soils, hours of hard work and skillful application are indispensable. Terrain can be altered to some extent, e.g. terraced or drained, if soil productivity and rainfall justifies the effort. Soils can be made more productive or restored, but only to the extent determined by their origins and state of development. The many hours of hard work invested must be rewarded in better yields.

Differences in climate, terrain and soils will obviously determine what techniques or practices should be attempted. The same technique applied to different soils in the same climate will have different results. By the same token a soil may be so extensive as to occur in a range of climates, e.g. the case of arenosols in the Sahelian zone, and the effectiveness of a particular method developed for one arenosol may not be attained on another with a different climate. In considering strategies for extending soil and water conservation practices, one should first examine the likelihood that there are climate/terrain/soils combinations in other places that are comparable to those where effectiveness of practices has been documented.

By combining our growing knowledge of what is working well for African farmers, revealed through case studies with our knowledge of African soils and climate revealed on continental maps, we should be able to locate and map, at least on a reconnaissance level, those physical environments where effective, documented techniques could be further extended.

[1] Shaikh, Asif et al. 1988. *Opportunities for Sustained Development in Africa. Vol. II. Case Descriptions*. Washington DC: US Agency for International Development ;Critchley W., Chris Reij, and A. Seznec. 1992. *Water Harvesting for Plant Production. Vol. 2. Case Studies and Conclusions from Sub-Saharan Africa*. Washington DC: World Bank (World Bank Technical Paper 157); Veit, Peter G. 1995. *Lessons From the Ground Up; African Development that Works*. Washington, D.C.:World Resources Institute. 75 p.; Reij, C., I..Scoones and C. Toulmin (eds). 1998. *Sustaining the Soil*. London:EarthScan.

Using maps to find the potential range of soil and water conservation practices

Maps of soils and agroclimates of Africa prepared by FAO can now be displayed over base maps using GIS programs. Prior to 1995, the maps were available only in limited number as hard copy. They have been digitized by FAO and are available on CD-ROM.[2] The base maps now available as the Digital Chart of the World became available around 1995. These maps and sites have been assembled, along with base maps prepared from the Digital Chart of the World, within a map-based information management resource (DEVECOL/Africa)[3]. Numerous case studies documenting effective soil, water, agroforestry and other environmental resource management experiences have been geo-referenced and included in the DEVECOL/Africa information resource. The analyses which follow are based upon the examination of these maps and case studies.

The analytical question posed by this exercise was:

> Can available digital maps of soils and climate (and the associated "attribute" information[4]) help to identify soil/climate environments where known soil and water conservation (SWC) practices could be effective and could be promoted?"

Practices in two different regions were examined – the Yatenga Plateau area in Burkina Faso and the Tahoua area in Niger. Exemplary SWC practices, notably the use of planting pits, have been documented in both areas. The soils and climate of the two regions are different, however.

Digital Maps as Information Resources

The technique of composite overlays, using transparent materials, has been employed by geographers and others for many years in the spatial analysis of multiple factors in the landscape. Now the same technique is greatly facilitated by GIS programs, which can simultaneously display and manipulate maps compiled at different scales. The information contained in the maps and associated to the mapped areas becomes a much more accessible resource than in its hard copy format. The various digital maps described next have been developed for display in vector format in the DEVECOL/Africa information resource.

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[2]FAO. 1996. Digital Soil Map of the World and Derived Properties,(Version 3.5, Nov. 1995); 1994. Digitized Maps of the Major Climatic Divisions and Lengths of Growing Period Zones for the Developing World(Release 1.1).. Rome: Food and Agricultural Organization of the United Nations.

[3] Freeman, Peter H. 1998. The use of GIS for Development Information Management in Africa. Revised version of unpublished paper presented at the 1st International Conference on Geospatial Information in Agriculture & Forestry, Lake Buena Vista, Florida, 1997.

[4]Attributes refers to information about a given map object, such as a bounded area representing a soil unit, that is contained in a table linked to the map object.

Information in the base maps

Digitized from 1:1 million scale aeronautical charts (Operational Navigation Charts) these maps include 1,000 foot contour lines, spot elevations, and streams, all indicative of general terrain characteristics, as well as roads and towns or cities, and numerous other details contained in over 25 different "layers" or databases (Fig.1). The DCW datasets for Africa were packaged by the World Resources Institute on a CD-ROM produced in 1996[5] that also includes political-administrative boundaries and their populations and major conservation and protected areas. These databases facilitated the geo-referencing of sites with documented SWC practices and served as the base map for displaying soils and agroclimate information. The base map information, when shown "underneath" information on soils or climate, allows the user to navigate to different places with ease as well as visualize terrain features not revealed in the soils map.

Information on soils

Maps in vector and raster format were created by FAO from the 1:5 million scale FAO/UNESCO soil map of the world[6] and packaged on a CD-ROM (Fig 2). Each map unit is an association of soils, normally consisting of two or more classes of soils, e.g. arenosol, although some contain only one class. Each unit is designated by a unique code beginning with the dominant soil, i.e. the soil class that occupies a greater extent than any other soil in the mapped unit. In most instances a descriptive qualifier provides additional information on the soils' physical or chemical nature, e.g. luvic arenosol(clay accumulation in the lower horizon). Also, in some instances a phase of the soil association is identified, e.g. if stony, if presence of hardpan or indurated layer, if presence of a high water table, etc. For the dominant soil and second most extensive soil, information is also coded for texture and slope. These maps can be displayed in vector format .

In addition to the digital soil maps, the CD-ROM contains a number of databases with information on mapped soil units(i.e. soils associations) and soil classes(See Annex 1). Information on physical and chemical characteristics of soils was obtained from 1700 soil profiles. The data were statistically analyzed and applied to the raster version of the map[7]. The raster cells are squares 10 km on a side (5 arc minutes). The raster version of the soils information was not used for the analyses reported in this paper.

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[5] Africa Data Sampler; a Geo-referenced Database for all African Countries. Washington D.C.: World Resources Institute. 1996

[6] FAO-UNESCO. 1977. Soil Map of the World 1:5,000,000; VI, Africa. Rome: Food and Agriculture Organization of the United Nations. 299 p. plus 3 map sheets.

[7] A digital map displayed in raster format, displays information in the form of square cells arrayed on a grid. The ground dimension of the cells varies according to the detail of compilation or precision of the information attached to each cell.

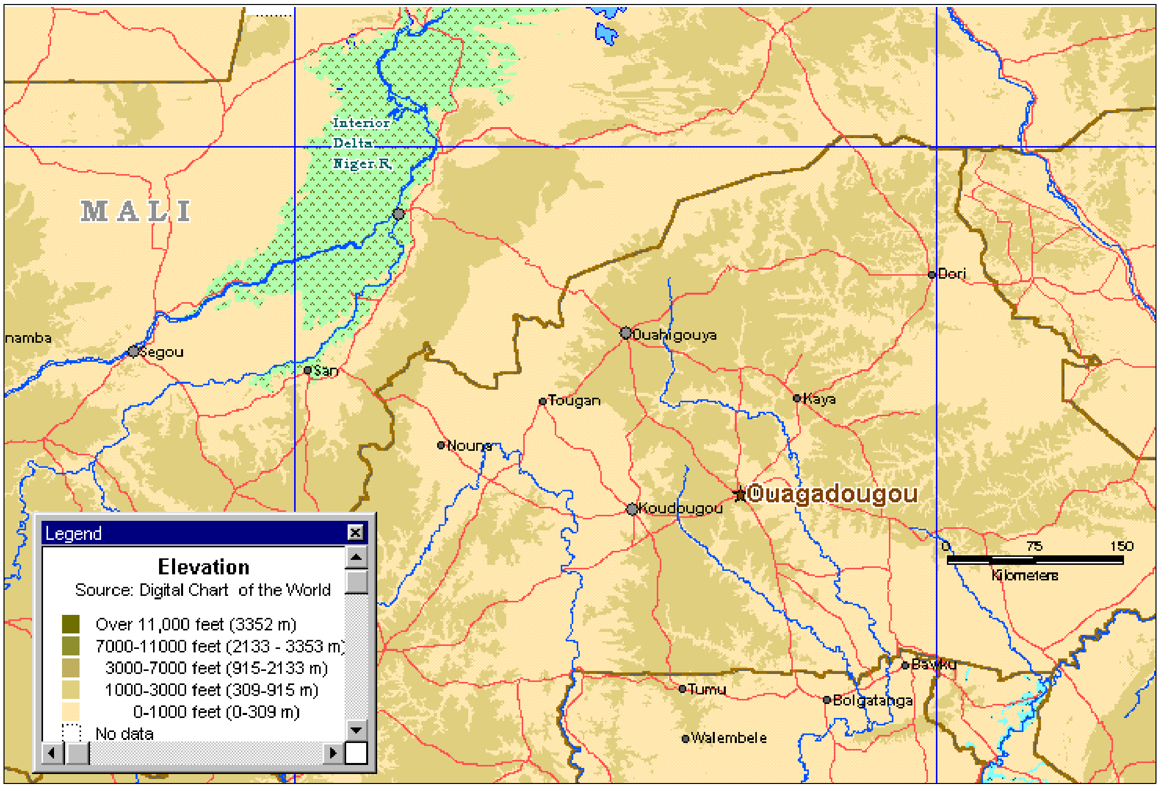
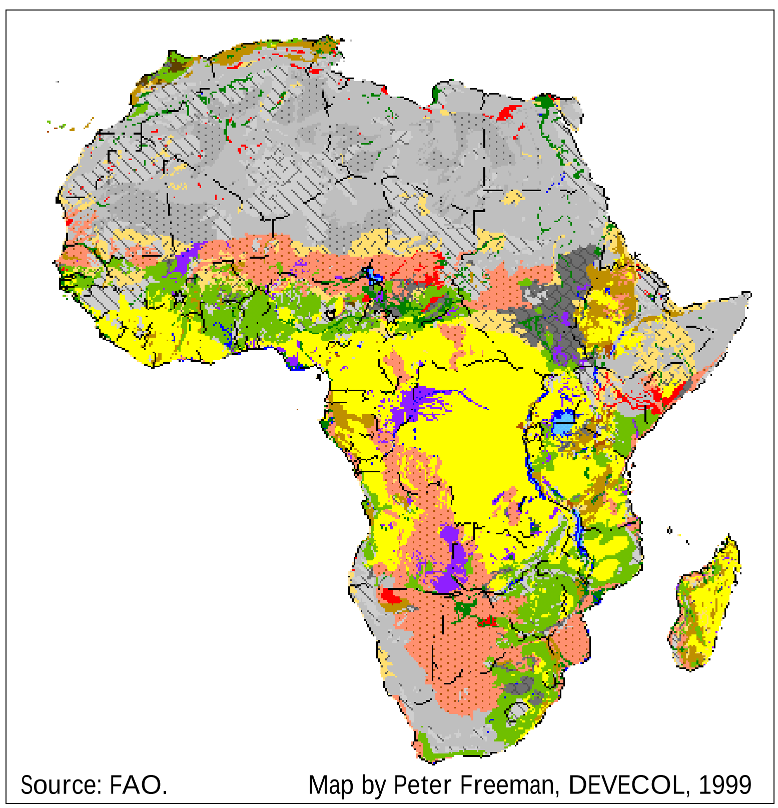


Fig. 1. Sample Base Map. Elevation ranges derived from Digital Chart of the World files reveal the pattern of uplands(darker shade) in Burkina Faso and neighboring Mali.

Fig. 2. FAO Soils Map of Africa. The digital version of the FAO/UNESCO soil map of the world has been made available on CD-ROM by FAO's Agriculture and Land Division in 1996. This small scale map groups the 167 distinct soil classes for display at smaller scales. At larger scales the boundaries of the individual classes are displayed.



Lastly, the CD-ROM contains data for creating maps that categorize soils according to their suitability for grain crops, beans, and for irrigation. A table with the percent of the mapped soil association suited to these different purposes was calculated and the maps can be displayed in vector format.

Limitations of the FAO soils association map for this kind of exercise are several. The soils on old landscapes in Africa show great heterogeneity within a small area. Many practices are tailored to local catena conditions(foot slopes, mid slopes, top slopes); soil texture, type of clay, and micro-relief are important determinants of the capacity of soils to hold water and nutrients. None of these are revealed by the mapped soils associations. Other limitations as well as advantages are further discussed at the end of this paper.

Information on agroclimate

FAO recently digitized the agroecological zone maps compiled almost 20 years ago[8] at the 1:5 million scale, as an input to the study on population supporting capacity in the developing world. Rainfall and temperature during the growing period were used to identify zones with different numbers of days suited to rainfed grain crop production, or length of growing period (LGP) zones. Length of growing period (LGP) is defined by FAO as the total number of days in a year during which rainfall exceeds one half potential evapotranspiration(Figs. 7 and 8). The agroecological zone maps also distinguish a number of temperature regimes during the growing period. The temperature regime of the entire region examined in this study corresponds to a zone with temperatures greater than 20EC during the growing season. Therefore the mapped temperature regime is not a geographic variable used in this exercise.

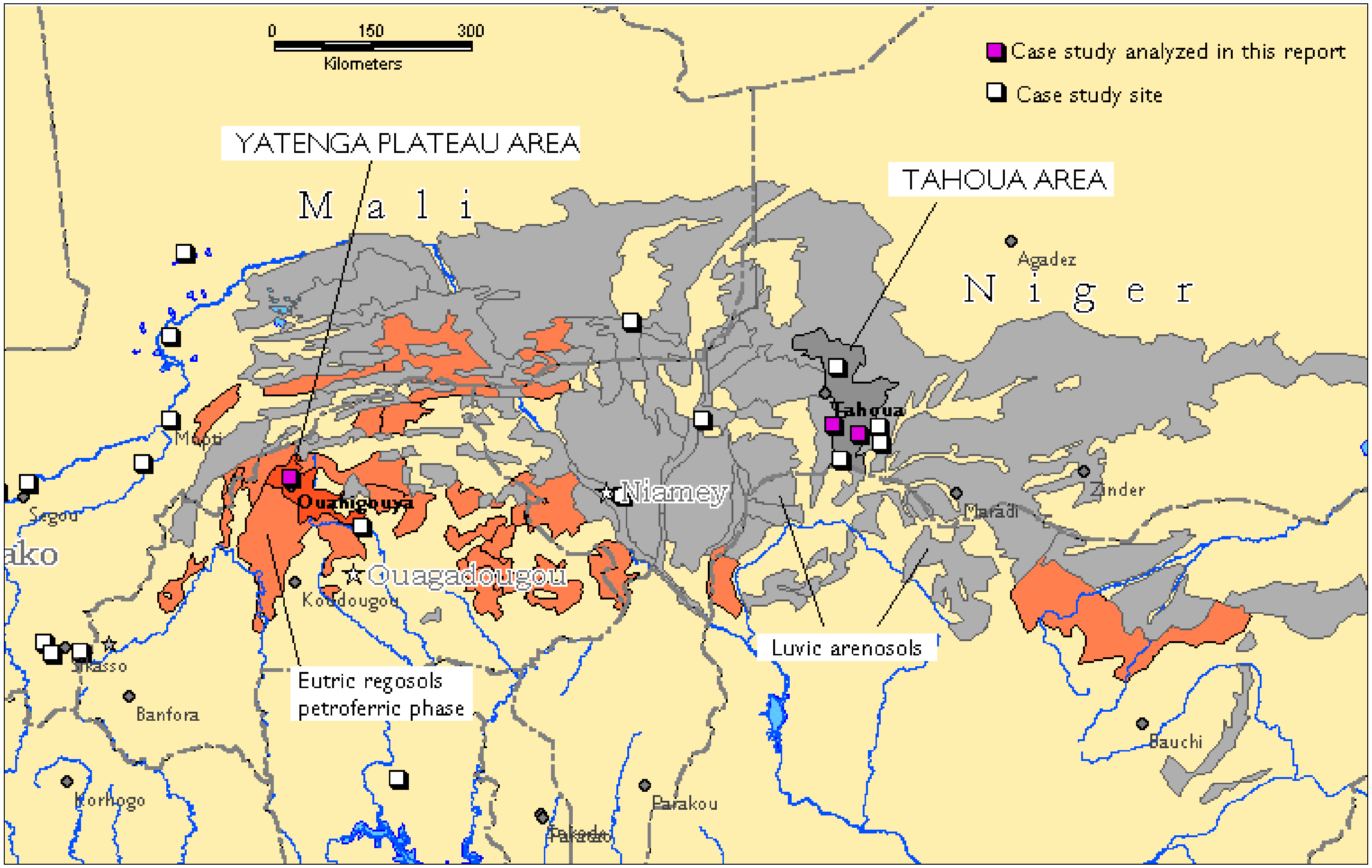
These agroclimatic interpretations used data available as of the late 1970's, and don’t average in the drought years of the 80's and 90's. They are rather imprecise(due to the small scale of compilation) for extrapolating local experiences. Also rainfall is variable in the drier areas. However, keeping in mind the inverse relationship between variability and amount of rain, especially at 500 mm/year or less, maps showing average values, such as the FAO agroecological zones map, can provide a useful overview of roughly similar agroclimates.

The Case Studies

A major feature of the DEVECOL/Africa information resource is the assembly of a large number of site-specific, documented experiences relating successes, and sometimes failures, in soil and water conservation, forestry, agroforestry, biodiversity conservation and more. They are geo-referenced and accessible in the form of a database record as well as in full text in the DEVECOL/Africa information resource.

[8]FAO. 1978. Report on the Agro-Ecological Zones Project; Vol. 1 Methodology and Results for Africa. Rome: Food and Agriculture Organization of the United Nations. 158 ps.

Fig. 3. Location Map showing the extent of the two types of soils associations and the case study sites.



Associations with Luvic Arenosols as the dominant or only soil are shown in grey. Eutric regosols with ironstone (lateritic) crust are shown in orange. The associations with the cases analyzed are shown in slightly darker tones.

Several cases were examined in depth. These were documents describing various soil restoration and water harvesting techniques on the Yatenga plateau of Burkina Faso and in the Tahoua region of Niger and published in two volumes: *Opportunities for Sustained Development: Successful Resources Management in the Sahel* (referred to hereafter as the "Opportunities study")[9] and *Sustaining the Soil* [10] . The first, published in1988 for USAID, includes 70 case studies of various kinds and scales of renewable natural resources management in Mali, Niger, Senegal, and Gambia. The second published in 1998, records the results of over 25 studies of soil and water conservation in Africa, focusing on indigenous techniques or farmer adaptations of introduced practices.

Analysis of case studies in relation to mapped soil and climate patterns.

Several map views were generated to allow analyses of case study sites against the soil map background and associated base map information. Two areas were examined in depth (see location map, Fig. 3). The first, in the Tahoua region, is shown in dark grey on the location map and corresponds to an association in which luvic arenosols are the dominant soil.(Characteristics of these soils are described below.) Other luvic arenosol associations with slightly different composition or terrain are shown in light grey. Four case study sites are located on this soils unit; two are examined in this paper. A third case study reviewed here documents practices on the Yatenga Plateau, on degraded lateritic soils(eutric regosols), shown in a somewhat darker brown color than other eutric regosol mapping units.

Tahoua region, Niger

The case studies summarized below record the results of soil restoration practices supported by foreign assistance projects in two areas southeast of Tahoua and found within a single FAO soil mapping unit (Ql12-2ab)(Fig 4). Most notable are the planting pits, or *tassa*, and *demi-lunes*(crescent shaped bunds on sloping land), supported by an IFAD project in the Illela district[11] in the southeastern part of this soil map unit. They have been spreading since the drought year of 1990, when their effectiveness in achieving better yields methods was observed. By 1995, an estimated 6000 hectares of degraded upland soils in the Illela district had been treated with planting pits and planted in millet. The *tassa* are also being used to restore degraded uplands in to the north of Illela District. In recent years USAID technicians in the field have

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[9] Shaikh,Asif, E.Arnould, K.Christophersen, R. Hagen,J Tabor and P. Warshall. 1988. Opportunities for Sustained Development: Successful Resources Management in the Sahel. Vol. III, Case Studies.

[10] Reij, C., I.Scoones and C. Toulmin (eds). 1996. Sustaining the Soil. London:EarthScan.

[11] Hassan, Abdou. 1996. Improved traditional planting pits in the Tahoua Department, Niger; an example of rapid adoption by farmers. In. Reij, C., I.Scoones and C. Toulmin (eds) Sustaining the Soil. London:EarthScan.

noted the spread of *tassa* on degraded soils along the road to the south and southeast of Badaguichri[12] within the same FAO soils association.

When the soil mapping unit within which these experiences are located is displayed against the base map its occurrence in uplands over 1,000 feet above sea level is apparent. The uplands of the eastern portion of the Illela district where this project is active fall within the soil association. The association also embraces the Keita district experience, described later.

Tassa are shallow pits approximately 30 cm wide and 10 to 15 cm deep dug on crusted soils of gently sloping or flat areas at the rate of 10,000 to 15,000 per hectare. On sloping areas, excavated materials are placed on the lower edge. The pits harvest runoff from the surrounding crusted soil, and capture rain- or wind-driven silt and organic matter to the benefit of millet planted in the pits. Germi-nating millet in the pits is also protected from the dessicating or cutting action of the wind.

Millet yields in two years (1993, a year of low and irregular rainfall and 1994, a year of "good " rainfall) were recorded on 470 farms in the Illela district with fields that were prepared with *tassa* and *demi-lunes*. Yields were measured from a variety of treatments: no treatment, *tassa* only, *tassa* with manure, and *tassa* with manure and superphosphate fertilizer. Technical analyses of the soils were not reported. Yields in plots treated with *tassa* were triple those of untreated areas. In 1994 *tassa*- treated plot yields were almost double those in 1993. Yields of millet ranged from 400 kg/ha (*tassa* only in 1994) to almost 1000 kg/ha (*tassa* + 0.5 kg manure). Triple super-phosphate in 1994 further boosted yields to almost 1500 kg/ha. Millet yields from plots with demi-lunes were comparable to those of *tassa*-treated plots.

Northeast of the Illela district in the Keita district, an Italian government-funded effort has supported a number of techniques to treat the plateau surfaces and watershed slopes in Keita within the same soils association. The "Opportunities" case study team, which included a soil scientist, documented the nature of the terrain and soils. The upper watersheds in Keita consist of hills and side slopes with limestone-derived soils having high water holding capacity, high fertility, and high pH. Undertaken in the late 1970's as an integrated rural development effort, the project sought to treat plateau areas, slopes descending from plateaus and hills to the valley areas, and the sandy soils of valleys. A watershed approach was followed, with treatment beginning at the higher elevations.

Trenches 3 meters long, 0,6 meters deep and 0,6 meters wide were dug by hand on these slopes at the rate of 600-800 per hectare and planted with native and exotic trees. Notwithstanding the scant 300 to 350 mm/year rainfall, the captured run-off helped trees grow to 2.5 meters in 18 months. On the gently sloping, hardened plateau surfaces, tractors were used to rip the crusted soils and build contour bunds, in order to slow and harvest runoff. Similar methods were used to

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[12] Personal communication with Mike McGahuey, USAID, Africa Bureau, Washington D.C..

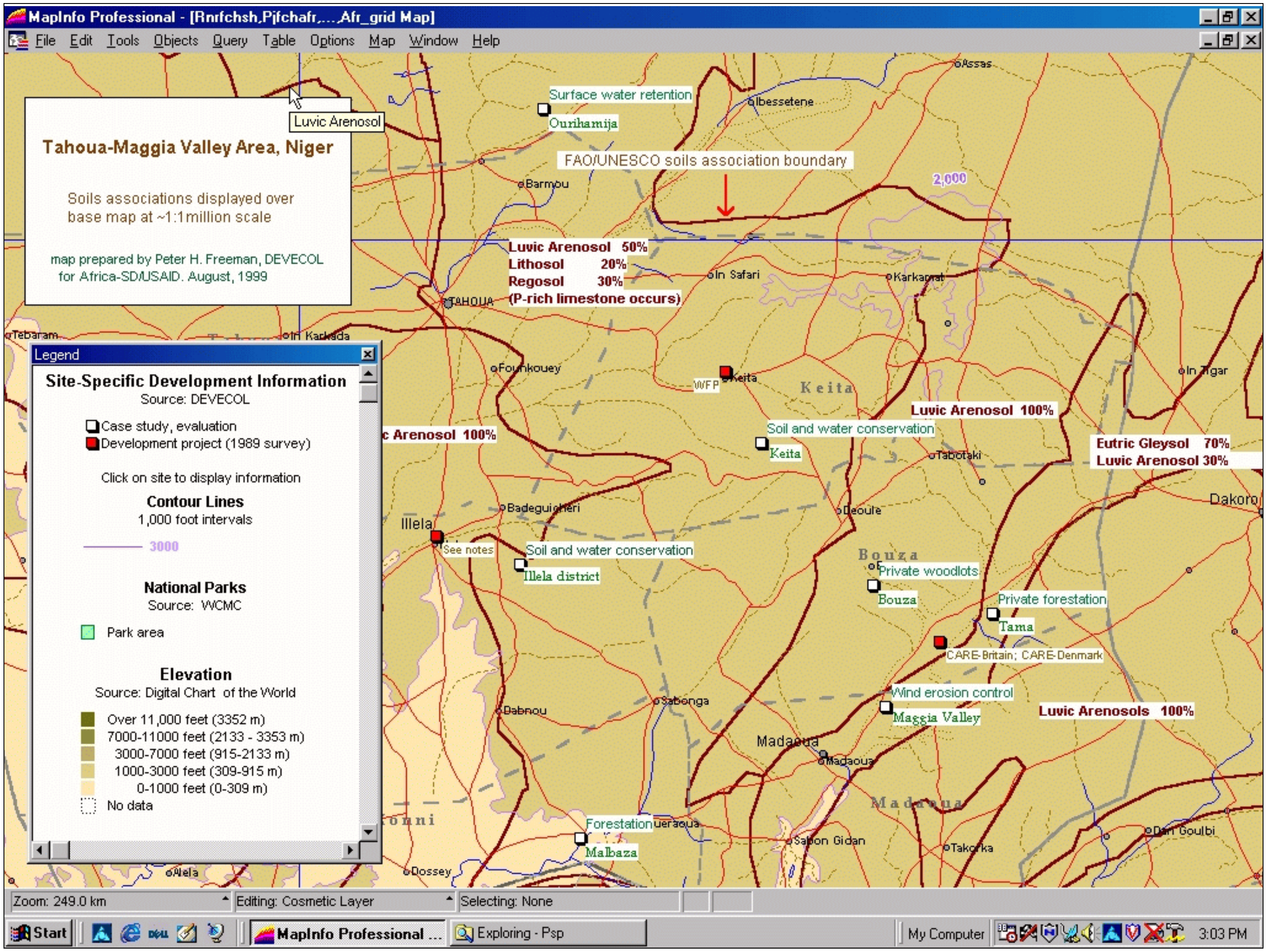

Fig. 4. Soil association boundaries (dark brown) superimposed over the base map of the Tahoua region. A number of soil and water conservation case studies have been documented within this soil association. The dashed grey lines are district boundaries; thin red lines are roads. Dashed brown lines are drainage ways.

build contour bunds on valley soils. In both places, surveying preceded bund construction. The results for millet yields on these soils were not recorded in this case study, but it was observed that farmers refused to buy triple superphosphate for these soils due to the risk posed by low rainfall. Donors have ceased supporting works built with tractors since they weren't kept up.

The soil map unit within which these two experiences are located differs in important ways from adjacent luvic arenosols. It is an association of three soils with only 50% being luvic arenosol. This is an inherently low fertility sandy soil with clay accumulations at depth. The rest of the unit is composed of regosols(30%) and lithosols(20%). Regosols are poorly developed soils that reflect the nature of the subsurface parent material(rock or other) from which they developed. Lithosols are very thin, rocky soils.

The Tahoua soil unit is characterized by the presence of a phosphate-rich limestone - the basis for nearby Tahoua's phosphate fertilizer plant. This is not the case for adjoining luvic arenosols which have developed over Continental Terminal rocks: sandstone, shale, marl, sand and clays according to the FAO monograph. Thus, the soils of this unit that overlie limestone or have developed over limestone-derived deposits (probably the regosol portion of the map unit) are benefitting from the phosphate as pointed out in the "Opportunities" case study on the earlier Italian-funded soil and water conservation effort. This may explain the good millet yields in the *tassa*-treated land of the Illela district, but it is not mentioned in the Illela case study.

Because this soil map unit is unique owing to the presence of P-rich limestone parent material, the yields or tree growth noted in the case studies may not be attainable on similarly classed soils developed over less fertile materials. However, a search, using GIS techniques of "all regosols or lithosols developed over phosphate- rich limestone" is not possible. The information on lithology(rock at the surface) of the map units is not contained in the database linked to the digital soil map.

Yatenga Plateau

The planting pits, or *zai*, which are reported to have spread over the past ten years on this plateau after being promoted by the Oxfam/UK funded Projet Agroforestier, are now well documented[13], and have become something of a model(Fig. 5). The area was visited by farmers from the Tahoua region, under the aegis of the IFAD project cited above.

OXFAM/U.K. initiated soil restoration actions on the plateau almost ten years ago, and the techniques evolved to the presently used *zai*, or planting pits, which harvest runoff from the surrounding hardened ground as well as fine materials, including organic materials, deposited by

[13]Ouedraogo, M. and V. Kabore. 1998. The *Zai*, a traditional technique for the rehabilitation of degraded land in the Yatenga, Burkina Faso. In: Reij, C., I.Scoones and C. Toulmin (eds) Sustaining the Soil. London:EarthScan.

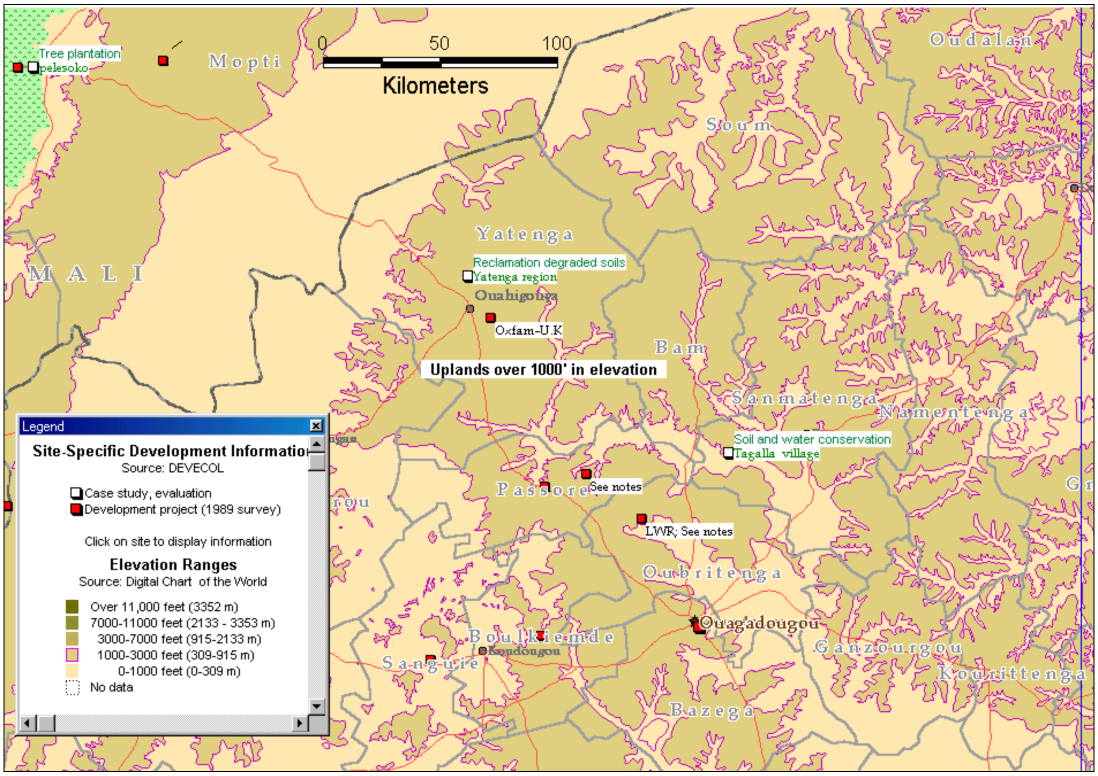

Fig. 5. Uplands over 1,000' in elevation are clearly seen in this view of the Yatenga Plateau area prepared from the Digital Chart of the World files. Plains and valleys below 1,000' are light yellow.

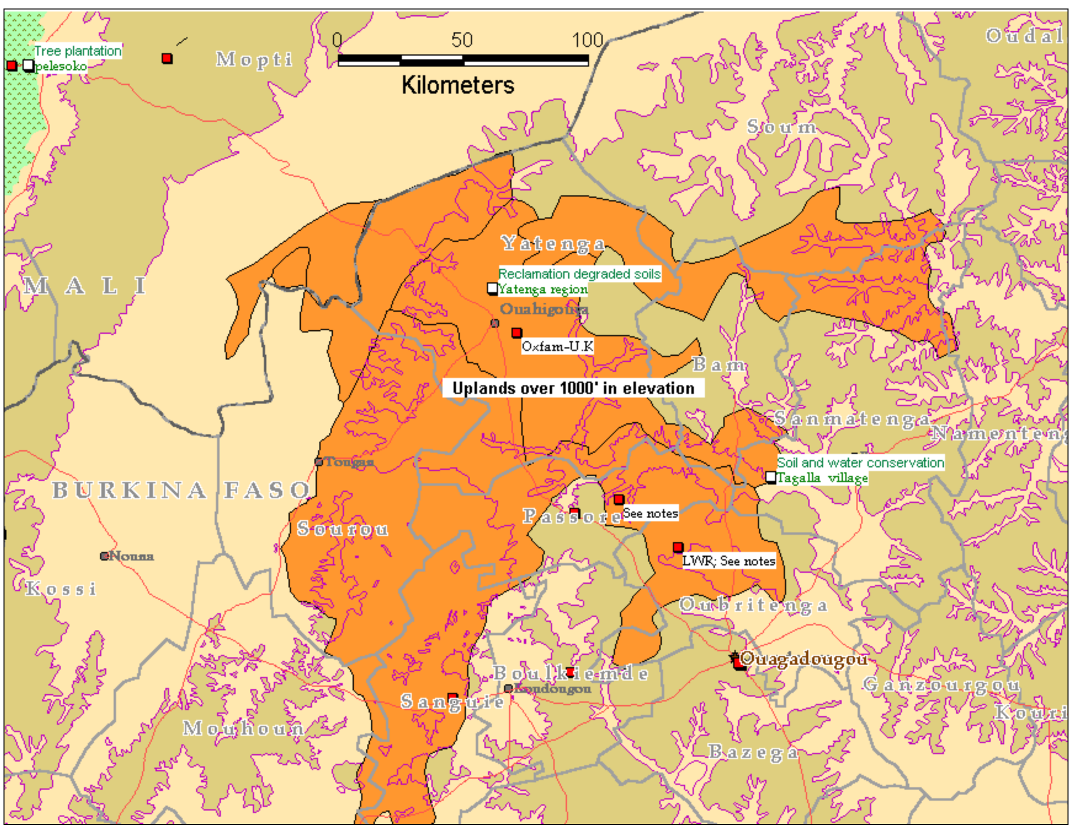

Fig. 6. *Zai* are reclaiming degraded plateau soils in Yatenga province that are classified as eutric regosols with lateritic surfaces (shown in orange). The FAO map of these soils was originally compiled on a 1:5 million scale base. Shown over the 1:1 million DCW base map the soil boundaries do not closely follow plateau borders. If compiled over the more detailed base map the map unit boundaries would probably be more congruent with the terrain patterns.

wind as well as water action. Sorghum or millet planted in the pits provides yields of 500 kg/ha to 1000kg/ha depending upon rainfall. Varieties planted and nature of the soil, other than its degraded state, were not mentioned.

The soil association on this plateau is characterized as follows: Eutric Regosol, petroferric phase, coarse texture, flat terrain (Fig 6). This signifies a soil with a cuirass or laterite, on the surface or near the surface. These soils have developed from Pre-Cambrian metamorphic rocks: quartzite, schists and – notably – greenstone (metamorphosed basalt),according to the FAO monograph. Greenstone contains the calcium-rich mineral epidote, among others, which may explain the "eutric" descriptor (that signifies high base saturation.) applied to the regosol. This is probably a factor in the productivity of areas that have been reclaimed using planting pits.
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Extrapolating the range of the practices

Areas with terrain, soils, and agroclimates generally similar to the uplands where the successful practices are reported were displayed and examined, using GIS.. The uplands areas of this part of Sahelian Africa are extensive, and the soil maps and agroclimate maps allows a selective view of those portions where soils and climate are similar. Several qualified interpretations can be made.

The soils of the Yatenga plateau and those of the Tahoua uplands are similar in that both are in flat to rolling upland areas, both are reported to be degraded and manifesting a hardened surface, and both have areas that had fallen into disuse before being recovered by planting pits. Also both areas are typified by regosols. The two soils are very different in their origins and their climates, however.

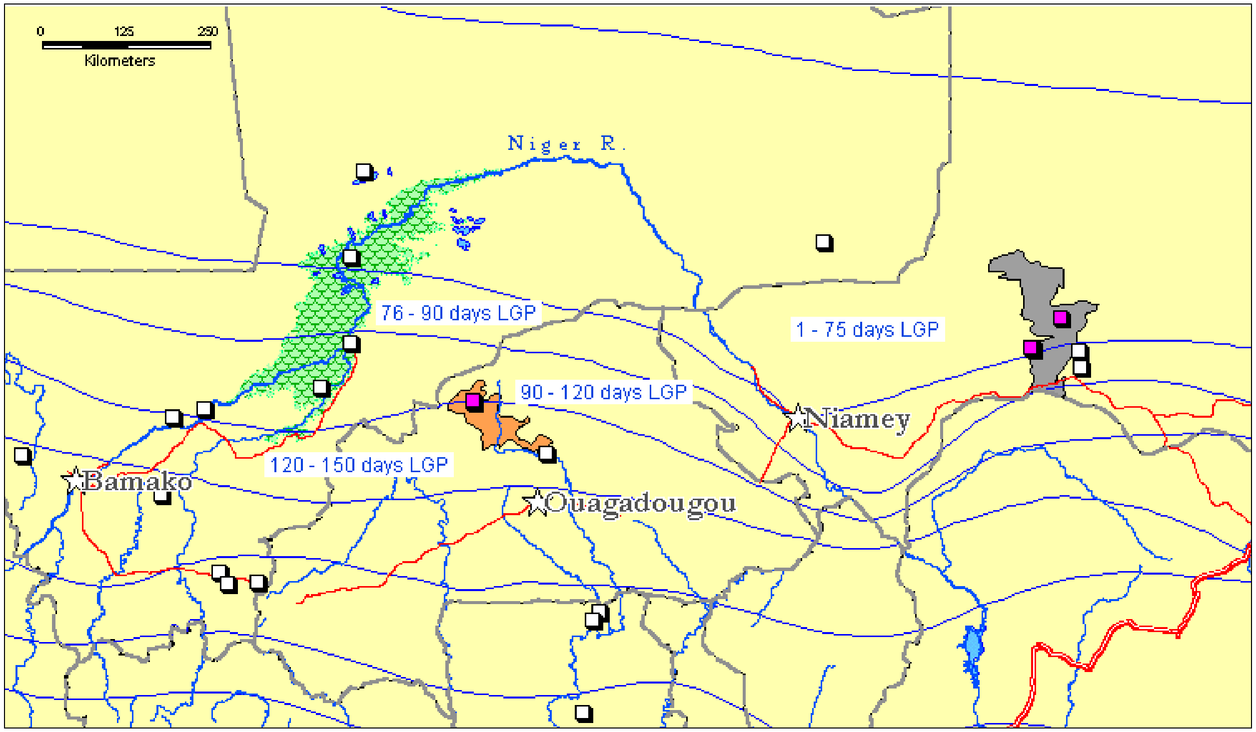
Agroclimate factors

The length of growing period map superimposed over the soils map shows that the two soils areas with documented planting pit sites are not in the same agroclimate (See Fig. 7). The Tahoua region, with less than 90 days of growing period, is much drier than the Yatenga plateau region which is largely within the 120-150 LGP zone, although the case study area is at the dry, 120-day LGP, limit of the zone.

This FAO agroclimatic map is of limited use for extrapolating the yields reported for areas treated with water harvesting techniques. Rainfall is highly variable in this part of Africa, with a coefficient of variation 20 to 25%[14]. In the Illela district, where *tassa* have proven so effective, rainfall averaged 368 mm/yr during 1980-87 whereas the 1950-89 average was

[14] Konate, M. 1984. Climate of the Sorghum and Millet Cultivation Zoness of the Semi-Arid Tropical Regions of West Africa. In: ICRISAT.Agrometeorology of Sorghum and Millet in the Semi-Arid Tropics; Proceedings of an International Symposium, ICRISAT Center, Patancheru India, November, 1982. Pages 101-113.

Fig. 7. Length of Growing Period Zones and Planting Pit Case Study Sites(purple)



The two soil associations within which the planting pit case studies (purple squares) are located are shown in orange (Yatenga Plateau) and grey (Tahoua area). The 1 to 75-day LGP is generally too dry for rainfed cropping and is mainly a pastoral zone. Raainfed millet and cowpeas are crops suited to the 75 to90-day LGP zone. Millet also does well in the 90 to 120-day LGP zone, along with short season sorghums. Sorghums grow best in the 120 to 150-day LGP zone.

448 mm.[15] Comparable averages were not documented for the Yatenga Plateau, which falls in the 500 to 700 mm per year average range, and enjoys somewhat less variability.

In general rainfed sorghum grows best with at least 120 days during which rainfall is greater than one half potential evapotranspiration. Millet is indicated in areas of 75 to 120 days of LGP. However, faster maturing varieties of sorghum such as IS-76 (85 to 95 days to maturity) and drought tolerant sorghums such as Kari/Mtama 1 (90 - 100 days to maturity) and others have been bred[16]. On the Yatenga plateau, both millet and sorghum were reported to be planted on land treated with planting pits while in Tahoua only millet was reported. This is consistent with the LGP designation of the area where the case study is located. Varieties planted weren't noted.

That Tahoua region planting pits should have yielded such good results at the apparent limit of millet cultivation is remarkable, but rainfall during the season of reported yields should be the first factor to be examined. For the years in which yields were recorded, rainfall amounts were not mentioned. Also rainfall will be slightly more effective at 1,000 feet above sea level, a factor not manifested in the LGP isolines, which were compiled over a smaller scale base.

The LGP zonation provides a reasonable view of the geographic distribution of rainfall and might be used to roughly map areas of comparable agroclimates where the results of soil or water conservation methods for crop growth might be achieved. However the LGP boundaries probably have an error of plus or minus 50 kilometers or more depending on the particular year and they don't show the influences of lesser elevation changes on rainfall efficiency.

Terrain and soil factors

The DCW base map includes 1,000-foot contour intervals, which, at the 1:1 million scale, reveal the major terrain features, i.e. valleys, uplands or mountains, areas of steep slopes. This terrain information revealed in the DCW base map provides important additional information about the mapped soils. The FAO map does not identify uplands, but when the two maps are superimposed(contour intervals and soil map units) the pattern is readily seen(Figs. 4 and 6). The "blocky" appearance of the soil unit boundaries in Fig. 6 reflects the smaller compilation scale(1:5 million) compared to that of the base map (approx.1:3 million).

A fairly large area in the northwest sector of Burkina Faso is uplands with soils classed the same as those in and around Ouahigouya and the Yatenga plateau area, as shown in lower map on page 12. Within the identified area reclamation of degraded soils using planting pits could be a fruitful practice, worth supporting. Condition of the soils, land tenure, nearness to markets, traditional landuses, and other factors would have to come into play, of course, in any assessment of an area-wide approach. However, the area so identified would serve to

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[15] Hassan, Abdou. 1998. Op. Cit.

[16] Chemonics, Inc. 1996. Seeds for Disaster Mitigation and Recovery in the Greater Horn of Africa. Washington D.C.: USAID, Office of Foreign Disaster Assistance.

delimit the region where these factors should be studied. The case study, which was written without the benefit of the FAO soil map, remarks on the fact that *zai* are “hardly used at all” in the provinces of Passori, Bam and Sanmatenga, where it observed that upland soils are equally crusted and population densities are high. It is clear from the soils map that the eutric regosols typifying the case study area are found in parts of these provinces, but not everywhere.

In the Tahoua region the luvic arenosols which name the soil association unit where the planting pits have been documented, also occur in adjacent soil associations. But the latter have no associated regosols and are not derived from limestone. While adjacent upland soils associations may also be degraded with surfaces sufficiently indurated to allow run-off capture, the absence of limestone could make a difference in the fertility of soils that accumulate in the planting pits as well as in the root development of plants, needed to reach moisture at depth. Thus the role of phosphate -rich limestone as a determining factor in the success of *tassa* seems clear (but needs to be confirmed in the case of the Illela *tassa*s), and its importance for tree growth in Keita was noted.. It appears that the regosol-over-limestone combination is the key to understanding the success of water harvesting efforts in this soils association.

The GIS analysis of potential ranges of this practice on other luvisols (or regosols) is limited because lithology is not an attribute in the databases that are linked to the mapped soils associations. Consequently, the extent of soils developed over limestone cannot be mapped using GIS. (A review of the lithology descriptions in the monograph revealed no other soils in Niger developed over limestone.)

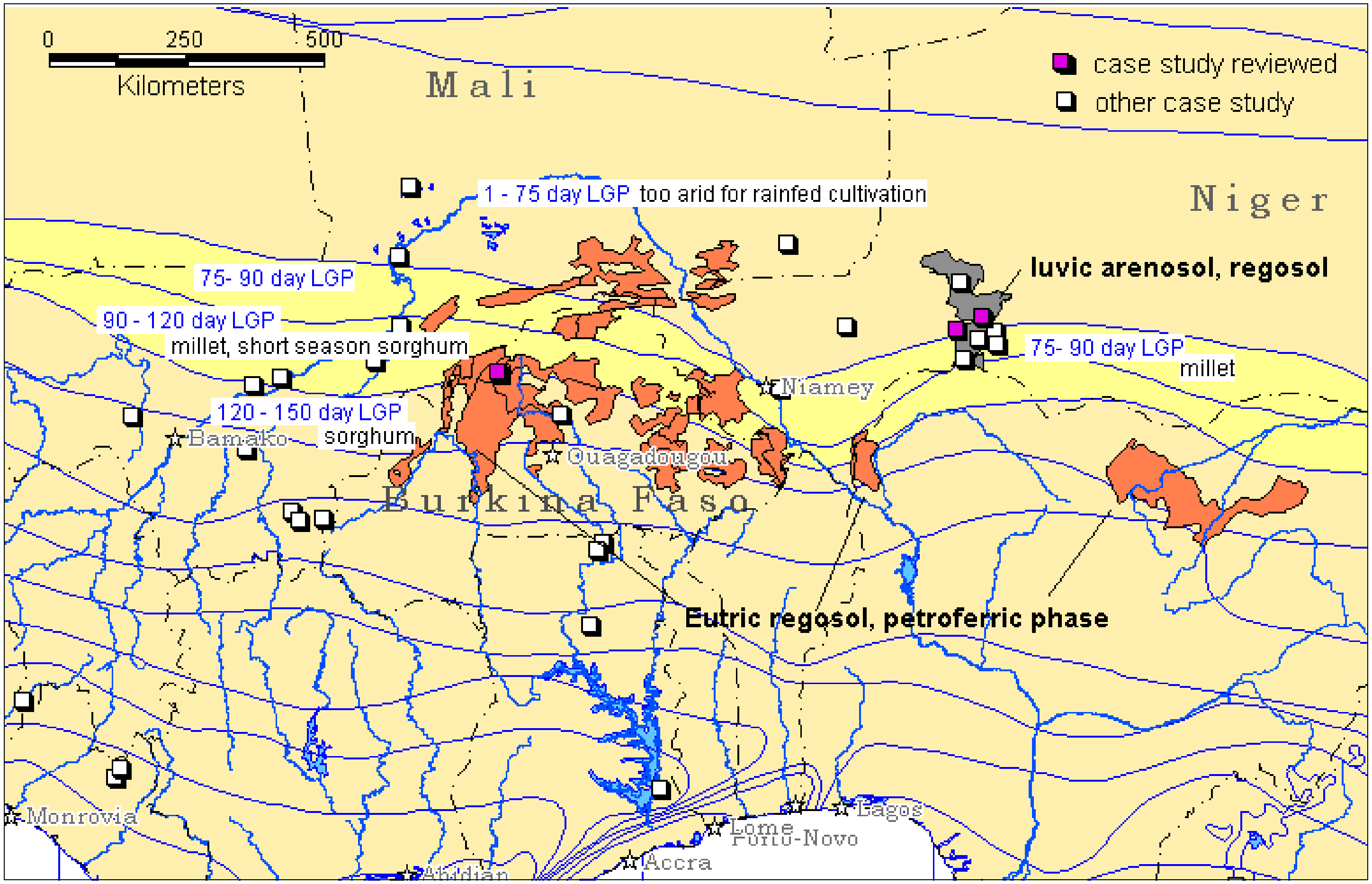
Extrapolation

In the case of the experiences in the Yatenga Plateau, the results achieved with planting pits are likely to be achieved on other eutric regosols with a laterite crust where rainfall is sufficient to make water harvesting worthwhile (Fig. 8). The degraded state of flat to gently sloping surfaces is an antecedent condition of course; it is more likely to have occurred in this drier zone, where regeneration is more difficult. This is the agroclimate with a 75 to 120-day LGP in which both millet and sorghum cultivation would be more feasible by virtue of water harvesting (Fig. 9). Within this agroclimatic zone, the total extent of lateritic eutric regosols is 3.2 million hectares.

In the 120-150 day LGP zone, where large areas of this kind of soil are also found, rainfall is higher and degradation of upland soils may not have been as severe. However, where surfaces have been denuded, *zai* could prove effective. Fig. 8 shows that within the 120-150 LGP zone the largest extent of eutric regosols, petroferric phase occurs in Burkina Faso; large areas also occur in Senegal Oriental, and Nigeria.

In the Tahoua case, the unique combination phosphate-rich soil parent materials and very low rainfall, is not found elsewhere and argues against spatial extrapolation of the experiences.

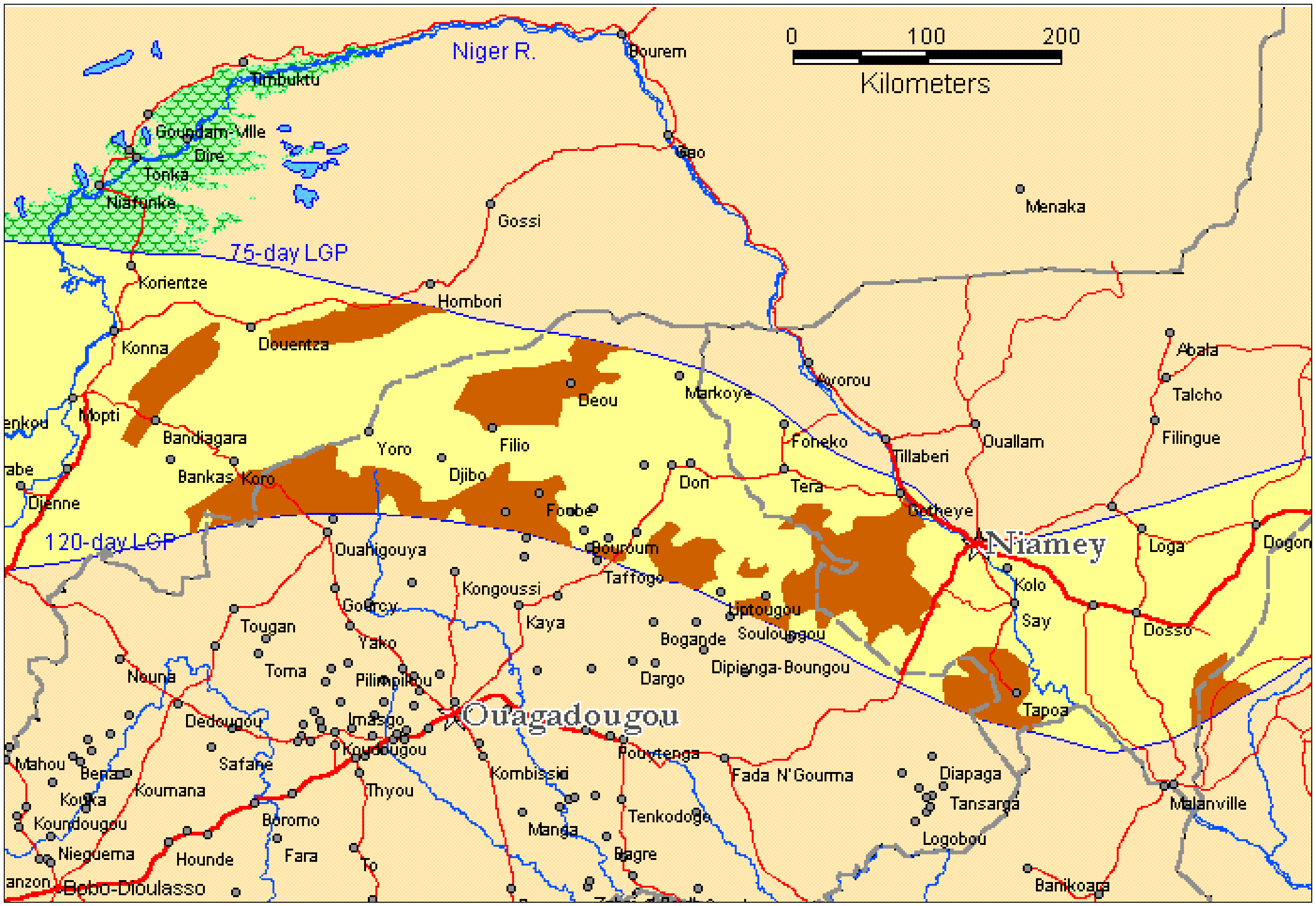
Fig. 8 Potential range of soil water conservation with planting pits



The yellow colored LGP[17] zones span the 75-day LGP to 120-day LGP – agroclimates of low and variable rainfall where soil water conservation could increase or assure yields of millet and sorghum. Areas of degraded eutric regosols within these agroclimates could be made productive with soil water conservation and harvesting methods such as the planting pits reviewed in the case studies.

[17] LGP, or length of growing period, is the total days when rainfall exceeds one half potential evapotranspiration.

Fig. 9. All Eutric Regosols, petroferric phase, within the 75-day to 120-day LGP Zone



All soils associations with eutric regosols, petroferric phase in Africa within the 75-day to 120 day LGP zone are displayed in this view. They are found principally in Burkina Faso, with smaller amounts in Mali and Niger. However, although eutric regosols are the dominant soil, they do not occur over the entire mapped areas; their total extent is 3.2 million hectares, or 60 % of the 5.4 million hectares occupied by this particular soils association within this agroclimate

Conclusions

Potential range of planting pits

The success of planting pits on the Yatenga plateau holds promise for other areas with degraded eutric regosols having laterite crusts. However, only in Burkina Faso, Mali, and Niger do similarly classed eutric regosols fall within the drier agroclimates (75-day to 120-day length of growing period) where water harvesting would make sense if degradation has rendered the soil denuded and unproductive. A total of 3.2 million hectares of such soils are found, though all are not degraded. (Crusted soils other than eutric regosols in these zones may also respond well to planting pits.)

The combination of terrain, soils, and climate contributing to the good results of planting pits in Tahoua are, on the basis of the materials examined, unique and not found elsewhere. In particular, the phosphate-rich limestone over which some of the soils have developed is not found elsewhere in Niger, and elsewhere in Africa it is found only in small areas.

The differing outcomes of the extrapolation analyses for these two instances underlines the significance of lithology for understanding the inherent soil fertility of regosols and for understanding the effectiveness of soil restoration methods for these soils, where effectiveness is measured by yield increases.

As regards the technique of geographic extrapolation of documented site-specific experiences in soil management, the analytical process can begin with digital versions of FAO maps of soils and agroclimate, but it does not end with them. As a first approximation of the geographic occurrence of areas worthy of attention for extending a method recorded in a site, the maps are very useful and areas can be quickly delineated. In subsequent analysis and planning of areas identified by this means, more detailed soils and climatic information must be examined, and demographic, cultural and economic factors relevant to the introduction and sustainability of such practices must be studied. The agenda of such studies, now well established in the sustainable development approach, is spelled out in the volumes from which the case studies featured in this exercise were drawn. The reconnaissance level geographic analyses illustrated in this paper illustrate how to identify areas that merit the cost of the additional studies.

The utility of digital maps

The small scale maps used in this exercise were originally assembled in order to help characterize the general environments of site-specific studies as a means of finding similarly situated studies. However, they proved far more useful in assessing the potential range of documented experiences than their scale or precision would suggest. This is partly explained by the ease with which maps at different scales and different combinations of maps can be examined using GIS programs. It is also due to the supplementary information associated with the FAO digital map, their attribute tables, and related documentation.

The cross-referral of site-specific documentation with mapped information related to soils and terrain was synergistic and increased the total information available for the analysis. In one of the cases studied(Yatenga plateau) the FAO maps contained more soil information than the case study documents. It is not unusual for case studies of development experiences to omit technical information about soils, climate and other physical environmental features. In contrast, the Keita case study contained more soil information than the FAO map; a soils scientist worked with the study team in this instance.

The graphic display, using GIS, of continental scale soils and agroclimate maps, on digital base maps together with site-specific information on actual experiences, makes possible a reconnaissance level analytical process and visualization of spatial relationships that is not possible using actual paper maps and reports. To the author's knowledge the use of small scale digital resource maps for analyzing the potential range of practices documented in site-specific studies for the purposes stated has not previously been attempted. This kind of analysis greatly facilitates the understanding of geographic patterns and the posing and answering of questions about site-specific experiences. General characteristics of soils and climate where these experiences are located can be examined in light of the experiences and their possible range of spread. However, the limitations and advantages of the various maps must be kept in mind.

Advantages and limitations of the FAO soil map

This digital map makes possible examinations of soil association patterns and occurrences that greatly facilitate the procedure of posing and answering questions related to soil influences and their geographic extent. The attribute information contained in different databases with links to the soils association polygons contributed to an understanding of the soils factors at play in the documented cases.

The potential for soil restoration in areas mapped as regosols appears to be strongly related to the minerals in the surface rocks. The digital soil maps don't include lithology as an attribute and can't serve to map this relationship. Other sources would have to be examined; in this exercise the FAO monograph accompanying the paper version of the original FAO/UNESCO soils map of Africa held useful information, and the case studies provided complementary information. Surface geology maps would be valuable for better understanding regosols.

Given the scale of compilation, the FAO soils map does not, and could not, generate local information on field capacity or CEC, organic matter and other chemical characteristics useful to understanding both results of experiences as well as their potentials elsewhere. The tables with such data, based on statistical results of the 1700 profiles analyzed in 1992, are useful for understanding the nature of different soil classes. However, they are of limited use for understanding the individually mapped associations.

Lastly, the confidence with which geographic extrapolation of site-specific experiences can be interpreted varies from one soils association to another according to its constituents. The more soils in an association, the more qualifications there will be to its usefulness in identifying other areas with soils comparable to those of the site. Thus, as the Keita area analysis demonstrated, it was the hillside soils, not the plateau soils, that were described as fertile and derived from limestone. These were interpreted to be the regosol portion of the association, i.e. not the dominant soil, which is a luvisol. *Tassa* weren't tried on the plateau soils in Keita, but were used successfully on plateau soils in Illela, and are reported to be spreading on other degraded (crusted, bare) plateau soils. Whether or not the plateau soils are regosols derived from limestone can't be known from the maps or case studies, but the good responses to *tassa* in Illela district support the deduction that they are.

Advantages and limitations of the Digital Chart of the World base map

This map is essential for locating site-specific studies and related features. It is an essential complement to the soils and agroclimatic maps, particularly as a source of information on terrain and drainage. The DCW base map does not include all populated places, i.e. villages of various sizes, and consequently will not serve to locate many named places, including some villages cited in the above-referenced case studies. However, the same case studies often mention distances and directions from larger town and cities which are featured on the base map, which along with an examination of other terrain features, such as streams and roads, makes possible an approximate location.

Advantages and limitations of the Length of Growing Period map

Although the length of growing period map delineates the general areas where a documented technique might be effective in respect to total moisture availability, the map does not lend itself to projecting or estimating different outcomes as measured by yield of a particular experience in the semi-arid zones. In these zones, average yields, like average rainfall, are of less predictive value than the coefficient of variation. Also in extrapolating the influence of a particular water conservation method on crop yields that has been recorded in a study, the precipitation values for the year(s) reported are an essential piece of information. This is all the more true for the interpretation of soil water conservation results. Likewise, in the interpretation of agroclimatic factors that explain soil erosion control experiences, results must be examined in light actual rainfall and rainfall events during the period reported upon, e.g. the duration and intensity of rains and the time of year of the most intense rains.

Advantages and limitations of working with maps of differing compilation scales

Both the soils and the LGP maps were compiled over a 1:5 million scale base map, which was the American Geographical Society map of Africa. When depicted over the more detailed 1:1 million scale DCW base map, incongruities related to the influence of elevation and terrain on soils and climate are evident. Thus the soils boundaries corresponding to plateau or uplands land forms will not coincide well with the DCW delineation of these land forms. Also, the somewhat cooler temperatures to be expected at high elevations compared to temperatures in lower elevation plains or valleys should affect rainfall efficiency and by extension length of growing period. Elevation differences of 1,000 feet can be shown using DCW data, but the LGP isolines do not reflect the possible influence on evapotranspiration in this part of Africa. (Elevation controls on temperatures in East Africa modify LGP patterns but, again, with much less precision than would have been possible had the DCW base map been used.). An awareness of the influence of elevation and terrain, as depicted on the DCW maps, on soils and agroclimate can help in the interpretation of the FAO maps.

ANNEX 1

Notes on the CD-ROM Digital Soil Map of the World

The CD-ROM contains both vector and raster files for all the regions of the world. Only the vector files were used for the present report.

The FAO taxonomy identified 25 classes of soils, however these are further divided into "sub-classes" by descriptors, resulting in a total of 167 classes in Africa. These in turn occur in different combinations with other soils to form associations, which are the mapped units displayed on the map. For Africa there are almost 6,500 unique associations or polygons.

Each mapped soil association is identified with a code, beginning with a letter symbol for the dominant soil class(S1), which occupies a larger portion of the association than any other soil – usually 50% or more. Associated soils are also identified in the code. Some units have associations of three or four soils, especially those with lithosols as the dominant soil. Others consist of only one class of soil.

For individual mapped units the following parameters are available and can be analyzed and displayed on the map or accessed in an information "window" from the map image:

Phases of S2 And S2
Hectares of S1 (dominant soil)
Hectares of S2 (next most extensive soil)
Texture and slope of S1 and S2
% of S1 and S2 not suited to different grain crops, beans or irrigation

Other data have been prepared in databases that, although not congruent with the map units, afford information about the soils classes that is helpful in understanding the potentials and limitations of different classes of soils.

Texture and terrain are presented in a separate database that aggregates associations that are similar into approximately 4632 units with the following data presented for each unit:

% coarse texture
% medium texture
% fine texture
% flat
% rolling
% steep

Information on soil chemistry is presented in a database (Sustxt.txt) derived from a statistical analysis of 1700 soil profiles in Africa, taken from a 1992 survey by FAO as well as from USDA data on African soils. It contains statistically derived average values for the following parameters, arrayed for each of the 167 soil classes found in Africa.

%sand topsoil(0-30 cm.....hereafter referred to as top)
%sand subsoils(30-100 cm ....hereafter referred to as sub)
%silt top
%silt sub
%clay top
%clay sub
pHwater top
pHwater sub

....and so on (top and sub)for the following and for each of three texture categories(sandy, medium, clayey):.

OC (organic carbon)
N (nitrogen)
BS (base saturation)
CEC (cation exchange capacity)
CaC03 (calcium carbonate)
BD (bulk density)
C/N (carbon/nitrogen ratio)

Annex 2 displays the values for the two soils described in this report.

These data also are presented in two tables, one for the top soil and one for the subsoil, that include statistical interpretations of the 1700 soil profiles for the above parameters, e.g. maximum, minimum, mean, standard deviation, and the like.

Annex 2

Average values for two classes of African soils, calculated from soil profiles

Source: FAO CD-ROM DSMW, data table sustxt.txt.

	Luvic Arenosol	Eutric Regosol
% sand topsoil(0-30 cm)	93	68
% sand subsoil(30-100 cm)	92	72
% silt top	3	15
% silt sub	3	15
% clay top	5	17
% clay sub	5	13
pH water top	6.3	6.4
pH water sub	6.1	6.8
OC (organic carbon)top	0.2	0.2
OC sub	0.12	0.45
N (nitrogen) top	0.02	0.06
N sub	0.02	0.06
BS (base saturation) top	74	83
BS sub	72	76
CEC (cation exchange capacity) top	3.5	10.2
CEC sub	3.2	6.7
CEC clay top	58	44
CEC clay sub	57	42
CaC03 (calcium carbonate) top	0.4	1.6
CaCO3 sub	0.4	6.4
BD (bulk density) top	1.4	1.4
BD sub	1.5	1.2
C/N (carbon/nitrogen ratio)top	10	9
C/N sub	5	7