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NiSOTER – a database for determining areas for soil and water conservation measures in degraded landscapes

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Abstract
In research and development projects various soil and water conservation (SWC) measures have been developed. However, a major obstacle to implementation, success and local adoption is the poor knowledge of soil and terrain features and their spatial variability in the landscape. This study presents the evaluation of the NiSOTER (Niger SOil and TERrain) database for indicating intervention areas suitable for specific SWC techniques and discusses the potentials and limitations of this method in the Southwest of Niger, for example ridge cultivation can be promoted for large areas in that region. The NiSOTER-database is shown to be suitable for SWC planning at different scales. It is outlined, however, that the evaluation results rather serve as a first basis for targeting suitable areas for specific SWC techniques, since the local agro-ecological and socio-economic environment as well, needs to be taken into consideration.

Introduction
The sandy soils of the West-African Sahelian zone are highly susceptible to wind and water erosion. Soil and nutrient losses occur at alarming rates, particularly at the beginning of the rainy season when pastures and crops are not yet established, thus the erosive forces of heavy convective storms impact upon the bare soil surface (Sterk et al. 1996). Traditional erosion control practices, for example mulch application, pasture- and long-term fallow management no longer keep pace with the increasing land use (Graef and Haigis 2001). Therefore various soil and water conservation (SWC) measures have been developed and are recommended by research and extension services (Roose 1996, Vlaar 1992). They include the stabilisation of the soil by stone lines, terraces, herbal strips and various forms of agro-forestry measures, for example planting and management of trees, shrubs and windbreak hedges. Conservation tillage techniques such as minimum tillage, zero tillage and ridge cultivation are also considered to be highly beneficial (Köller et al. 1998, Klaij & Hoogmoed 1993). However, SWC measures need to be adapted to specific soil and landscape characteristics such as soil texture or terrain slope and also to socio-economic circumstances of the target population. Thus, knowledge about the spatial distribution of

potential intervention areas, especially in the variable landscape of the Sahel, is a must for extension approaches to be sustainable. Hence, the NiSOTER (Niger SOil and TERrain) -database (ISRIC 1993, Graef 1999) has been applied, to evaluate and indicate potential intervention areas suitable for specific SWC techniques. As an example the selection of suitable terrain for ridge cultivation is presented and discussed in more detail.

Study area and methods

The surveyed area covers 24.000 km² in the SW of Niger. In geological terms the study area is situated on the transition of the Precambrian West African craton or "Liptako" region (basement complex) to the "Continental terminal" (CT) deposits of the "Iullemeden basin", both extensively superimposed by Pleistocene and Holocene eolian and fluvial sediments. The climate is semi-arid with a mean annual precipitation ranging from 350 to 600 mm and with average monthly minimum and maximum temperatures between 16 and 42°C. The precipitation shows a high variability in time, space, amount and intensity (Graef and Haigis 2001). The vegetation changes from grass savannah in the North (Southern Sahelian zone) through bush savannah to tree savannah in the South (Northern Sudanian zone).

For management of soil and terrain data the SOTER (Soil and Terrain Digital Database) approach (ISRIC 1993) was used, which is applied in several countries worldwide. It includes analytical attribute data and GIS-based spatial terrain data. Satellite data (Landsat TM), soil transects and several types of thematic maps were used for the soil and terrain inventorying and mapping at the scale of 1:50.000 to 1:100.000 (Graef et al. 1998). Transects of several km length with a total distance of 192 km and over 1000 augerings were studied to obtain a) an extensive inventory of soil types, their characteristics and their distribution in the terrain and b) spatial information about terrain features. The total NiSOTER database comprises 500 profile data sets and their analytical data and 53 terrain components.

SOTER parameters related to the feasibility of SWC techniques (comp. Vlaar 1992) such as soil structure, texture, bulk density, hydraulic conductivity, infiltration rate, terrain slope and slope length were evaluated and classified with SQL (standard query language) database queries. For ridge cultivation the following suitability requirements were postulated: a) erosion prone topography (slopes >1%), because sloping land yields more economic benefit with ridging as compared to level land (Köller et al. 1998) b) absence or lack of protective soil cover (crop residues, cover crops, mulch) and c) sandy topsoils which require less draught force for soil tillage, because donkey-drawn mechanisation schemes are at present more profitable in Sahelian subsistence cropping than for example weeding by hand (Köller et al. 1998).

Results

Terrain and soil characteristics

The landscape is marked by extensive plains and plateaux. Cover sand terrain units account for half of the area, but other areas include patches with thin sand deposits, thus the cover sand area comprises 82%. The proportions of the main geological substrates are 4 : 1 : 1 for CT, granite basement and sedimentary rocks respectively. In the CT landscape the plateaux areas (24%) exceed the pediment areas (20%). Hills and plateaux on the basement, however, account only for 1% of the surface compared to 18% of pediment plains. This is because the plateau-forming CT-sediments are almost absent in the Liptako region. Valleys and depressions influenced by water and sediment influx cover 9% of the area. The relief intensity can be expressed by the ratio of slope (≥3 %) areas per geological area: sedimentary rocks (0.71) > granite basement (0.36) > CT (0.22). Not only the area of slopes but also the pediments' slopes are higher on the sedimentary rocks. The high variability of slope inclinations even within relatively flat terrain components such as plateaux and pediments (Table 1) indicates highly undulating mesorelief.

Table 1 Terrain features and suitability of SWC measures in the Sahel

	Plateaux[1]	**Plateaux with thin sand cover**	**Slopes >3%**	**Pedi-ments**	**Level cover sands**	**Sloping cover sands**	**Cover sand valleys**
area (%)	13.1	6.5	5.3	8.8	16.9	3.1	4.8
slope (%)	0.5-1.8	0.8	3.5	1.1-1.7	0.7-0.9	3.1	0.9-1.1
SD	± 0.4-1.7	±0.5	±2.0	±0.4-0.7	±0.3-0.8	±1.5	±0.7-1.2
veg. cover (%)	27	43	35	35	47	46	50
SD	±14	±15	±19	±19	±23	±22	±24
soil textures	sL	S, lS	sL, S	sL, S, X[2]	S, lS	S, lS	S, lS
ridging	-[3]	-	(+)[4]	0	-	++	++
mulching	-	++	(0)	++	++	++	+
zai	+	0	(++)	++	0	0	0
herbal stripes	-	+	(+)	+	++	++	++
half-moons	+	-	++	+	-	-	-
stone lines	0	0	++	+	+	++	+
dikes	0	-	0	++	-	-	-

[1] commonly used and rather suited for pasture, [2] stone cover, [3] ++: highly suitable, +: moderately suitable, 0: no effect, - unsuitable, [4] (...) indicates positive effects if SWC techniques are applied at high density

Soil types (FAO 1988) generalised in terms of texture, development stage and depth are Arenosols and Cumulic Anthrosols (39 %), Arenic soils (soils having a sandy surficial stratum thicker than 20 cm above stony or heavy-textured material, 22 %), Leptosols (20 %), Acrisols, Alisols and Luvisols (7 %), Cambisols (6 %), Vertisols, Gleysols and Fluvisols (5 %) and others (1 %). This corresponds to 38% sandy soils, 22% sand-covered stony or loamy-clayey soils, 20% shallow stony soils and 18% loamy-clayey soils.

Terrain suitability for soil and water conservation techniques

The standard deviation of terrain and soil features in Table 1 exhibit a high spatial variability of slopes, vegetation cover and soil types in the landscape. This variability occurs in micro as well as macro scales (Lamers & Feil 1995, Van Duivenbooden et al. 1997). The land suitability assessment of SWC techniques presented in Table 1 is thus derived from average terrain component parameters. The outcome indicates that the sloping areas and the plateaux with hardpan soils should be reserved for pasture or reforestation measures such as half moons or zais (planting holes). For the large cover sand pediments, plateaux and valley systems a set of different SWC measures can be applied, each of which depends on the soil texture and slope prevailing in the terrain and of course on the financial resources. For example ridging, mulching, zais and herbal stripes are low cost interventions whereas half-moons, stone lines and dike constructions require high labour investment (Roose 1996).

In this context the NiSOTER database has been applied for a low resolution (1:50.000 scale) overview. However, combined with the GIS and extensive database queries more detailed information can be derived as well. For example considering terrain slope, mechanised ridge cultivation has a high potential in major parts of the study area. Half of the total area of 24.000 km² includes slopes steeper than 1 % (Table 2). About 19 % of the area are highly prone to water erosion due to slopes greater than 2 %.

Table 2 Proportion of different slope classes in the study area

slope (%)	**<1**	**1 - 2**	**2.1 - 3.5**	**3.6 - 7**
proportion within study area (%)	53	28	10	9

Table 3 Proportion of sandy soils in sloping terrain (>1%)

Proportion of sandy soils (%)	**0-25**	**26-50**	**51-75**	**76-100**
proportion in sloping terrain (%)	18	23	25	34

Most of the plain land (<1% slope) belongs to the CT plateau areas and the cover sand pediments. Slightly sloping land (1-2 % slope) prevails in the pediment areas, while steeper slopes (2.1-7 % slope) occur near plateau escarpments. The high slope angle variability within all terrain components (Table 1) indicates, that the potential intervention area for mechanised ridge cultivation is possibly underestimated at this mapping scale (1:100.000). Considering sloping terrain components the major proportion of them (59 %) can be assigned to terrain components with predominantly (50-100%) sandy soils (Table 3). In Figure 1 the spatial distribution of these areas with high potential for mechanised ridge cultivation are indicated. The level cover sand pediments, which are preferred for agriculture, were excluded from the evaluation, because they do not yield sufficient economic benefit with ridging as compared to erosion prone sloping land (Köller et al. 1998). The results show, that ridge cultivation on the basis of donkey drawn mechanisation schemes has a considerable potential in a large part of SW-Niger. Despite the high variability of the soil and terrain characteristics in the region, the terrain components for potential introduction of ridging are located in coherent areas (see Figure 1). This is convenient for targeting and establishing operational areas and infrastructure for extension efforts.

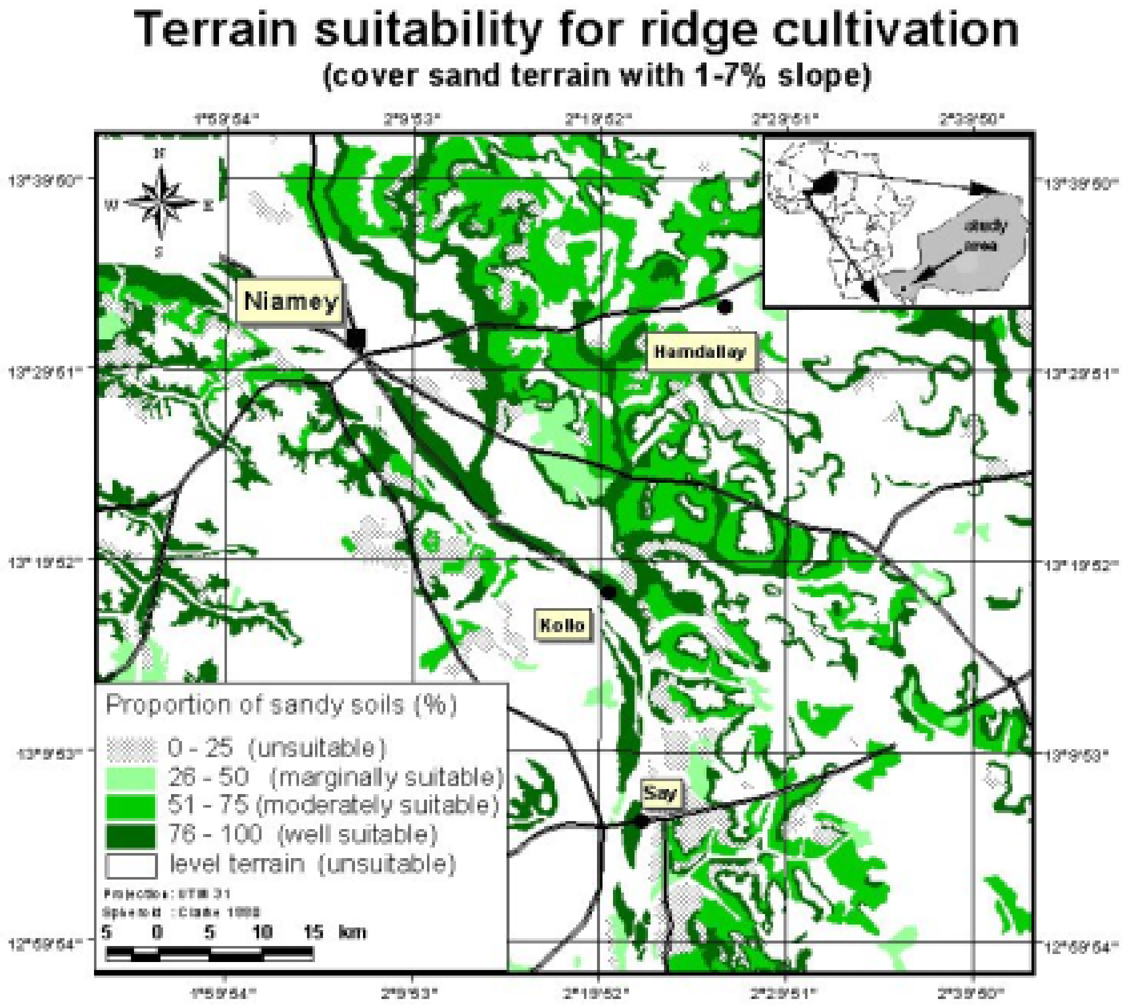

Figure 1: Distribution of terrain components with 1-7% slope and their percentage of soils with sandy surface cover, most suitable for ridge cultivation

Discussion

Considering the deterioration of natural resources and the increasing cropping risks in the Sahel SWC techniques are being promoted to encourage stable yields. They mitigate the risk of poor spatial and temporal rain distribution, while including a soil and nutrient conservation aspect (Vlaar 1992). Viewing the pressing time horizon of Sahelian farmers, the agricultural risks posed by annual climate fluctuations are critical (Graef and Haigis 2001). Therefore, short-term risk avoidance techniques are more likely to be adopted. However, they should also consider watershed management, integrate improved cultivation techniques (for example ridging, manure application) and long-term anti-erosive measures (for example herbal lines, terraces) along different terrain types as stressed by Dugué et al. (1993) and Roose (1996).

For this purpose the NiSOTER database offers an operational tool. It is applicable both for large scale planning of SWC measures and where combined with a GIS as a tool for targeting potential areas for implementing SWC measures such as ridging while providing at the same time additional information with respect to technical questions (for example stone content, crusting). Regarding for example the landscape presented in Table 1, different soils, slopes and terrain positions require specific measures. Furthermore they need to be adapted to the local scale conditions (for example spacing of zais depending on slope or soil type, Vlaar 1992). The proposed evaluation method of

SOTER databases for SWC measures is also applicable to other regions and climates, however, the respective mapping scale and precision (Herrmann et al. 2001) is of great importance for reliable evaluation results.
Despite the suitability of large areas in SW-Niger for mechanised ridge cultivation and its favourable yield and land conservation effects (Klaij and Hoogmoed 1993, Köller et al. 1998) it has not yet found widespread application in the region. This is probably due to the high cropping risk depending on factors such as rainfall distribution and soil characteristics which also include a considerable financial risk to the farmer. Therefore, a more combined evaluation of both the local bio-physical and socio-economic environment prior to SWC implementation would be desirable (Roose 1996, Patrick 1998). Since SWC techniques vary considerably concerning both short- and long-term yield and economic benefit, the applicability on the farmers' time scale is crucial (Lamers & Feil 1996). Another important consideration is that spot-like high inputs contradict the farmers' need for risk dispersion imposed by the spatially variable rainfall (Graef and Haigis 2001). This aspect of risk dispersion on the farmers' scale, however, is not in the scope of the NiSOTER evaluation of SWC measures but needs to be integrated with the SWC extension process. In general the methodology presented here is applicable not only to the dry Sahelian landscape in Niger but also to other climatically different regions worldwide.

Conclusions

The NiSOTER-database is suitable for SWC planning at different scales. The applicability of SWC techniques can be indicated for each terrain component throughout the landscape and detailed information from the inherent soils types is provided. This information can be used in various fields of SWC research and for extension projects. However, parameters such as rural infrastructure as well as socio-economic and ecological aspects have to be considered on different time scales as well. Sustainable techniques likely to be adopted need to be short-term oriented, economically viable and in accord with the local agro-ecological and social environment, but they have to include simultaneously long-term sustainability aspects. Therefore, the evaluation results of this study should not be interpreted as a general recommendation for example for mechanised ridging in SW-Niger. They rather serve as a first basis for defining future operational areas for specific SWC techniques that are suitable with respect to the biophysical conditions.

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