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Land Suitability for Crop Diversification and Yield Potential of a Drained Swamp Area in NW-Tanzania

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Abstract

To meet the increasing demand for food, land use planning in NW-Tanzania recently focuses on swampy valley bottoms which are considered to have the highest production potential. Land development also aims at crop diversification for nutrition improvement and self-sufficiency. Locally drainage projects are required to enable dry-season crop production. The pilot project data of the Bigombo Valley Development Project are used to calculate the actual and potential lowland suitability according to the parameter method suggested by SYS et al. (1991 AND 1993) for 9 different food crops. Local food crop priorities disagree strongly with the climatic suitability. Landscape and soil suitability is calculated for three different soil wetness levels. The potential land suitability for all crops is only marginal at the sub-optimal wetness level but moderate to very suitable at the optimum drainage level. When fully reclaimed, this land is very suitable for potatoes, beans and soybeans while moderately suitable for onions, green peppers, cabbage, tomatoes, sweet potatoes and maize.

The quantitative assessment of five food crops according to the FAO-AEZ method (FAO 1979) confirms their suitability ranking except for potatoes. By relating the estimated figures to yield data for maize, the magnitude of the management factor is assessed, being similarly crucial for the crop production potential as soil wetness conditions.

1 Introduction

In the tropical highlands of NW-Tanzania with predominant Ferralsols (FAO-UNESCO-ISRIC 1990) and a bimodal rainfall pattern, swampy valley bottoms are considered to have the highest potential for agricultural development due to higher fertility of the Gleysols, constant water supply and lack of erosion (NGARA DISTRICT COUNCIL 1997). Land use planning aims at increasing food crop production by dry-season wetland cultivation and crop diversification to raise the local nutritional standards and provide some cash cropping.

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In this context the Agriculture Development and Improvement Programme of Rulenge Diocese requested an exemplary assessment of the potential land suitability for crop diversification at their water scheme in Bigombo valley.

This assessment had two main objectives:

1. To qualitatively assess the physical land suitability for nine food crops according to the local priority list and identification of production constraints,
2. To quantitatively assess the crop production potential for the five most important food crops.

2 Study area, materials and methods

2.1 Physiography of the study area

The Bigombo Valley Development Project is located in the Northwest of Tanzania at approximately 2°44'S and 30°37'E at an altitude of 1400 m. Its physiographic unit is a flat valley floor in roughly N-S orientation flanked by smooth hills on the western and steep hills on the eastern side.

Geologically the precambrian basement complex prevails. The Karagwe-Ankolean formation consists of acid sedimentary and partly metamorphic rocks. While the mean annual temperature ranges around 20°C there is a distinct difference between day- and night temperatures. The highly variable amount of rainfall in the two rainy seasons reaches nearly 1000 mm/year. Flooding and excessive wetness due to poor drainage conditions characterize the hydrological situation of the valley floor which led to the formation of a papyrus swamp. Leptosols, Cambisols, Ferralsols (upland) and Gleysols (lowland) are the most frequent soil types in the region.

Traditional agriculture is confined to subsistence food crop production during the long rainy season from February to May in the upland area. Due to highly unpredictable rainfall, yields are often low and occasionally fail completely. To meet the increasing demand for food crop production, an elaborate water management system was implemented in Bigombo valley near Rulenge town in 1973. Mainly beans and maize are cultivated in the lowland area during the dry season. Presently this water scheme needs rehabilitation.

2.2 Land resources inventory of the study area

Climatic data has been recorded since 1971 at the FAO Climatic Station Rulenge. Landscape data was taken from detailed topographical project maps. Bigombo Valley Development Project reports also provide information on land use (HOTTINGA 1984, VAN OORT 1987). A detailed local soil survey and analysis was carried out in 1996/97 by the Institute of Soil Science, University of Bonn. The corresponding mapping unit number in the Land Resources Inventory of Ngara District (NGARA DISTRICT COUNCIL 1997) is Val.o with an extent of 39,720 ha (10.6%).

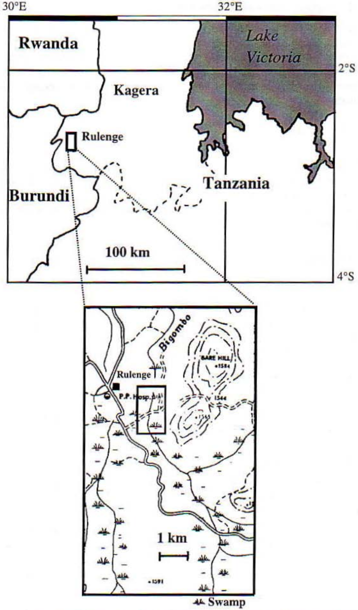

Figure 1: Location map of Bigombo Valley Development Project near Rulenge town in NW-Tanzania

2.3 *Description of the selected land use type*

The envisaged land use is dry-season cultivation of beans (*Phaseolus vulgaris*), maize (*Zea mais*), tomato (*Solanum lycopersicum esculentum*), Irish potato (*Solanum tuberosum*), cabbage (*Brassica oleracea*), green pepper (*Capsicum annuum*), onion (*Allium cepa*), soybean (*Glycine max*) and sweet potato (*Ipomoea batatas*) by smallholders at low management level. During the wet season the valley bottom soils are unusable due to waterlogging.

2.4 *Crop requirements*

For assessment of the land suitability the crop requirement tables in Land Evaluation III from Sys et al. (1993) were used, modified according to local conditions. Main changes involve the deletion of precipitation characteristics (since on the valley floor crops are grown on stored water) and soil drainage conditions: an imperfect drainage with a water table at approx. 50 cm depth is optimal for dry-season cultivation and rated accordingly.

3 Qualitative land evaluation of the Bigombo valley lowland area

Evaluation of physical land suitability is carried out by matching crop requirements and land characteristics. In this evaluation the parametric method is used rating the relevant characteristics on a scale of 0 to 100 (for optimum conditions). Subsequently indices are calculated by multiplication according to the Storie method (I = A x B/100 x C/100 x...; where I is the index, and A, B, and C are the ratings...) which gives comparatively low results (SYS et al. 1991).

Within the order S (suitable) suitability classes are defined as S 1: very suitable (index 75-100), S 2: moderately suitable (index 50-75) and S 3: marginally suitable (index 25-50); below the order is N: unsuitable (index 0-25). The nature of the constraint is indicated at the subclass level by addition of a modifier, here c: climatic limitations, w: wetness limitations, f: fertility limitations.

3.1 *Climatic suitability*

Depending on crop specific requirements, climatic suitability here refers to up to 12 climatic characteristics related to the 3 groups: temperature, relative air humidity and radiation.

With just 2 climatic stations in the Ngara district, the FAO Climatic Station Rulenge provides the only reference data for the Southern part (approx. 200,000 ha). As local rainfall variability is of no concern for dry-season wetland cultivation this assessment of climatic suitability is relevant for valley cultivation at similar altitudes on a regional level.

To illustrate the estimation of climatic suitability according to the parameter method Storie index, an example is given in Table 1. Of each group of climatic characteristics the lowest rating is chosen for calculating the climatic index (I_c).

Table 1: Climatic suitability ratings for cultivation of beans in Bigombo lowland, 1st July to 31st October

Growing cycle	Lowland	
	Data	Rating
Precipitation of growing cycle (mm)	not relevant	
Mean temp. of growing cycle (°C)	20.1	95
Mean min. temp. of growing cycle (°C)	12.3	99
Relative humidity of development stage (%)	57	98
Relative humidity of maturation stage (%)	62	90
n/N of development stage	0.59	96
n/N of maturation stage	0.52	86

Climatic Index (I_c): 95 x 90/100 x 86/100 = 74
n/N = Sunshine hours per day/day length

The appraisal of climatic suitability is confined to the crop growing period which is at this site determined by the lowering of the groundwater table after flooding in the previous rainy season. The start of the crop growing season is set at the likely date of July 1st. For beans, tomatoes, potatoes, green pepper and soybeans it lasts till the end of October; for cabbage, onions and sweet potatoes until November. The local maize variety takes until end of December to reach maturity (VAN OORT 1987). For tomato- and onion-nurseries the month of June is included in the calculation.

Climatically the lowland area is very suitable for onions, irish potatoes, green peppers and nearly beans (Table 2). Moderate climatic constraints are:

- for maize cultivation the ripening stage coincides with the months of fewest sunshine hours per day due to the long growing period of local varieties (180 days).
- for tomatoes, green peppers and cabbage the marked difference between day and night temperatures (14°C) is rather unfavourable. Management practices try to reduce it for young tomato plants by shading (bent banana leaves) or wrapping up (grass). Cabbage is furthermore affected by high air humidity prevailing in the lowland area.
- for sweet potatoes the relatively low mean temperature of the growing cycle is the most limiting factor.

Table 2: Climatic suitability ratings for food crop diversification in Bigombo lowland

Food crop priority ranking	Climatic suitability index class		Food crop climatic suitability ranking
1. beans	74	S 2	4
2. maize	45	S 3	8
3. tomatoes	57	S 2	7
4. (Irish) potatoes	81	S 1	2
5. cabbage	65	S 2	6
6. green peppers	80	S 1	3
7. onions	92	S 1	1
8. soybeans	70	S 2	5
9. sweet potatoes	43	S 3	9

3.2 *Landscape and soil suitability*

The typical profile of lowland soils classified as Mollic Gleysols (FAO-UNESCO-ISRIC 1990) consists of a thick (27 - 40 cm) greyish-black topsoil and a grey, strongly mottled (hydromorphic) subsoil underlain by a weathering zone in transition to bedrock at approx. 2 m depth (Table 3).

Table 3: Soil analysis data of a representative wetland profile in Bigombo

depth cm	horizon symbol	sand %	silt %	clay %	C_{org} %	N %	C/N ratio
0 - 5	Ap1	6.5	53.6	39.9	4.97	0.41	12.1
5 - 20	Ap2	6.0	53.7	40.3	4.63	0.44	10.5
20 - 32	Ah/Cg	6.8	52.9	40.3	1.33	0.14	9.5
32 - 130	Cg1	12.4	52.9	34.7	0.38	0.07	5.4
130 - 150	Cg2	74.6	19.4	6.0	0.05	0.00	---

depth	pH H_2O	Ca	Mg	K	Na	Sum	CEC	base saturation
cm	(1:2.5)	cmol(+)/kg soil						%
0 - 5	5.8	8.2	3.6	0.14	0.4	12.3	25.2	49
5 - 20	5.9	8.9	5.3	0.15	0.3	14.7	26.4	56
20 - 32	5.8	5.2	2.8	0.05	0.3	8.3	13.5	61
32 - 130	5.1	2.6	1.3	0.05	0.2	4.2	8.1	52
130 - 150	5.7	0.7	0.4	0.01	0.0	1.1	1.8	61

Table 4: Landscape and soil suitability rating for cultivation of beans (incl. water control) in Bigombo lowland

	Lowland	
	Data	**Rating**
Topography (t)		
Slope (%)	0	100
Wetness (w)		
Flooding	F 0	100
Drainage	imperf.	100
Physical soil characteristics (s)		
Texture/structure	SiCL	100
Soil depth (cm)	>100	100
Soil fertility characteristics (f)		
Apparent CEC (cmol (+)/kg clay	23.2	94
Base saturation	54	100
Sum of basic cations (cmol (+)/kg soil	12.6	100
pH (H_2O)	5.9	93
Organic carbon (%)	4.0	110

Land Index (LI): 100 x 100/100 x 100/100 x 100/100 x 94/100 x 93/100 x 110/100 = 96 f
Flooding class F 0: no flooding
Drainage class "imperfect": groundwater-table at approx. 50 cm depth
Texture: depth weighted average (over 1 m)
Apparent CEC: total mineral CEC x 100/% clay (at 50 cm depth)
Base saturation: weighted average (over 1 m)
Sum of basic cations (Ca, Mg and K), pH and organic carbon: weighted average of the topsoil (0-25 cm)]

Regarding general landscape and soil suitability (Table 4) the topography of this flat valley floor is optimal for crop production. So are the soil physical characteristics of the very deep, fine textured Gleysols. Textures range from clay to silty clay loam, without any coarse fragments. Improved by the still high organic carbon content (3 - 5 %) their topsoil structure is very favourable. Soil fertility is slightly limiting with regard to moderate acidity for sensitive crops only. The apparent cation exchange capacity (CEC) of the clay fraction is slightly above or closely below the optimum (≥ 24 cmol(+)/kg). Among the three soil fertility characteristics base saturation, sum of basic cations and pH, the most limiting is pH (H_2O) with topsoil average values of 5.6 to 6.1. Since the development of the thick mollic topsoil is much better than the usual optimum with an organic carbon content being mostly more than double the crop requirement, an exceeded rating of 110 (SYS et al. 1991, I p.67) is attributed. According to these criteria, soil fertility is high with fertility index values of 75 to 97 for the different food crops.

Within this evaluation method no further differentiation with regard to single bases is made, so possible imbalances/antagonisms and deficits are not considered. These Gleysols have a marked K-deficiency which constitutes a fertility limitation (k: < 0.2 cmol(+)/kg; SANCHEZ et al. 1982) which has not yet been recognized.

However, the major constraint is soil wetness limiting the growing period by flooding and/or poor drainage. There is great local variation with regard to wetness conditions due to the present deterioration of the water scheme (Table 5).

In places where both flooding and poor drainage occur during the crop growing season, the former swamp conditions are restored and Papyrus grows again. Index values by the Storie method drop below 25 which renders the site unsuitable (order N).

Land improvement by elimination of flooding needs to be achieved by technical means (repairing of the dams, maintenance of main canals). Full reclamation up to optimal drainage conditions supported by individual on-site management practices like construction of raised beds could raise the potential landscape and soil suitability enormously. Liming could further enhance the suitability to an index of 100 for all crops but would have a marked effect only for tomatoes, cabbage and green peppers.

Table 5: Landscape and soil suitability of Bigombo lowland

	Actual suitability				**Potential suitability**	
area with:	**flooding and poor drainage**		**poor drainage**		**imperfect drainage (here: optimal)**	
	Index	class	Index	class	Index	class
beans	24	N	48	S 3w	96	S 1
maize	23	N	45	S 3w,f	91	S 1
tomatoes	21	N	41	S 3w,f	83	S 1
(Irish) potatoes	24	N	48	S 3w	96	S 1
cabbage	9	N	38	S 3w,f	75	S 1/S 2
green peppers	21	N	41	S 3w,f	83	S 1
onions	9	N	38	S 3w,f	75	S 1/S 2
soybeans	24	N	48	S 3w	96	S 1
sweet potatoes	24	N	49	S 3w	97	S 1

3.3 *Land suitability*

For the total evaluation the climatic index is first transformed by the formula:

$R_c = 16,67 + 0.9 \times I_c$ where R_c = climatic rating, and I_c = climatic index

into a rating and then multiplied with the landscape and soil index divided by 100 according to the Storie method. Only the order suitable is considered.

Table 6: Land suitability ratings after partial and full land reclamation:
Case b: poor drainage/partly reclaimed

	Climatic rating	Landscape + soil index factor	Land suitability index	class
beans	83	0.48	40	S 3w,c
maize	57	0.45	26	S 3w,c,f
tomatoes	68	0.41	28	S 3w,c,f
(Irish) potatoes	90	0.48	43	S 3w,c
cabbage	75	0.38	29	S 3w,c,f
green peppers	89	0.41	36	S 3w,f,c
onions	99	0.38	38	S 3w,f
soybeans	80	0.48	38	S 3w,c
sweet potatoes	55	0.49	27	S 3w,c

Case c: optimal drainage/fully reclaimed

	Climatic rating	Landscape + soil index factor	Land suitability index	class
beans	83	0.96	80	S 1c
maize	57	0.91	52	S 2c,f
tomatoes	68	0.83	56	S 2c,f
(Irish) potatoes	90	0.96	86	S 1c
cabbage	75	0.75	56	S 2c,f
green peppers	89	0.83	74	S 2f,c
onions	99	0.75	74	S 2f
soybeans	80	0.96	77	S 1c
sweet potatoes	55	0.97	53	S 2c

This evaluation of potential land suitability clearly shows that soil wetness conditions are crucial for crop production in Bigombo valley lowland area (Table 6). Correcting water conditions improves suitability from class N to S1 and S2. Soil fertility limitations are less important and would require - besides K-fertilizers - liming only locally for acidity sensitive crops. Climatic limitations for several kinds of crops may be overcome by specially adapted varieties in future

4 Quantitative assessment of crop production potential

4.1 Yield prediction

For the main food crops beans, maize, Irish potatoes, sweet potatoes and soybeans the yield potential is also calculated according to the FAO-AEZ methodology (FAO 1979). Based on information on radio-thermal conditions the climatic production potential (CPP) is calculated first. In the second step water conditions at the site expressed as a factor of ≤ 1 (to account for yield reduction due to insufficient water supply) is included. Under the assumption of optimal water conditions after land reclamation here the water production potential (WPP) would be 1. In the third step soil and management are included. The relevant index of landscape and soil suitability as calculated by the parametric method is considered in terms of anticipated yield reduction ($Sy_p \leq 1$) due to such limitations.

Compared to good commercial (irrigated) yield levels, the physically attainable yields of beans and soybeans is very good, that of maize is moderate while the results for Irish potatoes as well as sweet potatoes are very poor due to low respiration coefficients (Table 7).

Table 7: Quantitative crop production potential

main food crops	CPP t/ha	WPP	Sy_p	Phys. yield potential t/ha
beans (dry)	2.8	1	0.96	2.7
maize (grain)	6.5	1	0.91	5.9
(Irish) potatoes (tubers)	6.3	1	0.96	6.0
soybeans (seeds)	4.0	1	0.96	3.8
sweet potatoes (tubers)	9.6	1	0.97	9.3

CPP = Climatic Production Potentential
WPP = Water Production Potential
Sy_P = Landscape and soil index, expressed as a factor between 1 and 0.

4.2 Matching predicted and observed yields

The figure of 5.9 t/ha for potential maize yields at high management level is confirmed by the only available yield data for maize in 1985 which is 4.5 - 6.5 t/ha on experimental plots (monocropping, optimal water supply, and management), with 0.9 - 1.3 t/ha average farmer's yields (VAN OORT 1985) and 0.65 t/ha marginal yields (HOTTINGA 1984). This implies that the management factor has a large effect ranging between 1.0

and 0.1 and thus determines the crop production potential at the same magnitude as the wetness limitations.

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