Soil nutrient status in vegetation communities of the Okavango Delta floodplains

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WETLANDS SUCH AS THE OKAVANGO Delta, located in semi-arid regions, are of great ecological, environmental and socio-economic importance. In most cases, however, few data exist on nutrient cycling in these areas. This paper presents preliminary results of an ongoing study, which investigates the influence of seasonal flooding on soil nutrient status in the different vegetation communities of the delta. Soil K, Na, and pH significantly increased with a decrease in soil moisture, with the values increasing from the primary floodplains to the islands communities. Available P, Ca and Mg decreased as the elevation gradient increased from the riverbed. Although nutrient status generally was highest in the floodplain vegetation areas adjacent to the riverbed, there was no significant difference in available P, Ca and Mg within the vegetation communities. Calcium levels in the different vegetation zones were more influenced by rainfall than floodplain vegetation community. Higher soil Ca was observed in the rainy season, while elevated Mg was recorded after the rains. Overall, these results indicate that flooding is an essential aspect of the Okavango Delta as it may be a primary source of some of the soil nutrients that support the high diversity of plants sustaining the delta's ecosystem.

Introduction

The Okavango Delta is a large, landlocked alluvial fan in the northwestern part of the semi-arid Kalahari basin in Botswana. It covers about 22 000 km^2, of which approximately 6000 km^2 is permanent swamp, 10 000–12 000 km^2 is seasonally flooded grasslands, and the rest is dry savanna.[1] Hydrologically unique, the Okavango system is second to the Niger Delta in Africa in extent and is the largest inland delta in sub-Saharan Africa. Seasonal flooding in the delta is influenced by local rainfall and inflow from the Angolan highlands, which converges to form two major tributaries, the Cunene and Cubango, that merge into the Okavango River, that then flows into the delta.

Water and its sediments are distributed across the fan by meandering and isolated channels, which are flanked by extensive swamps. The incoming water creates seasonal swamps, which can be characterized as primary, secondary, and tertiary floodplains and islands of various sizes. The floodplains support different vegetation communities. Primary floodplains are the lower-lying areas adjacent to a channel, which get flooded first and are flooded every year, while secondary floodplains are those areas lying above the flood line and receive flood waters in most years after the primary floodplains. The tertiary floodplains get flooded only in years of exceptionally high floods, whereas the islands remain dry throughout the year. Debris, sediments and chemical elements from the riverbanks upstream are hydrologically transported to the floodplains through surface ground flow and precipitation.[2] Owing to the location of the delta in a semi-arid region with high sand content (>85% sand), 97% of its annual inflow (7000–15 000 × 10^6 m^3) is lost to evapotranspiration and percolation, while only 3% is discharged and spread into the seasonal floodplains.[1]

The beneficial effects of flooding on soil nutrients include an influx of dissolved and suspended nutrients, accumulation of nitrogen and an increase in soluble phosphorus and silicon.[3] Therefore, wetlands of surface flow origin such as the Okavango are usually nutrient-rich compared with those wetlands of precipitation origin, which are generally nutrient-poor.[3]

Wetlands slow the passage of water and encourage the deposition of nutrients and sediments carried in water. Nutrient retention in wetlands makes them among the most productive recorded, rivalling even intensive agricultural systems. The floodplains support a high plant population and diversity.[4–6] Plant distribution on the floodplains is mostly according to elevation and soil moisture gradient, thereby giving rise to eight different vegetation communities.[6] These floodplains also support a large population and diversity of wildlife, thus soil nutrient status and replenishment are crucial to sustain continuous grazing by the fauna. Hitherto, there was little documented literature on the soil nutrient status of the Okavango Delta's seasonal floodplains.

In this study we investigated and evaluated seasonal soil macronutrient variations in the floodplains of Nxaraga, in the Okavango Delta. We also explored and report on the relationship between soil macronutrient variations and vegetation communities.

Materials and methods

Study area

The study site is located in the Nxaraga lagoon (19°35′S, 23°10′W) southwest of Chief's Island in Moremi Wildlife Game Reserve (Fig. 1). The Boro River, currently the main out-flowing channel from the delta, seasonally floods the area. The main months of flooding vary from May to December. Maximum average rainfall in the area is 550 mm yr^{-1}, with the main rainfall months being from November to February.[7] Annual mean temperature ranges between 25° and 40°C. The soils consist predominately of sand (>85%),[8] with a decrease in peat and other organic material with distance from the riverbed, thus creating an O horizon in the primary floodplains. Occasionally, depending on the sediment carried by the river, a thin O horizon may form in the secondary floodplains.

Soil sampling and analysis

Five permanent sampling plots were established in 1997 in each of the eight vegetation communities, namely, (i) *Alternanthera sessilis–Ludwigia stolonifera* (AS-LS); (ii) *Cyperus articulatus–Schoenoplectus corymbosus;* (CA-SC); (iii) *Miscanthus junceus–Digitaria scalarum* (MJ-DS); (iv) *Paspalidium obtusifolium–Panicum repens* (PO-PR); (v) *Setaria sphacelata–Eragrostis inamoena* (SS-EI); (vi) *Imperata cylindrica–Setaria sphacelata* (IC-SS); (vii) *Veteveria nigritiana–Setaria sphacelata;* (VN-SS); (viii) *Sporobolus spicatus–Cynodon dactylon* (SP-CD).[6] The locations of the vegetation communities in relation to the Boro River were in the order listed above; the AS-LS was the closest to the riverbed and the SP-CD community the most distant. The communities AS-LS to CA-SC are characteristic of the primary floodplains, while MJ-DS to IC-SS represent secondary floodplain; the rest are regarded as tertiary floodplain communities. Three replicate soil samples were collected from the rooting zone, that is, the top 30 cm (O/A_1 horizon), of each plot during the rainy season (mid-March), before flooding (mid-May) and after flooding (end of

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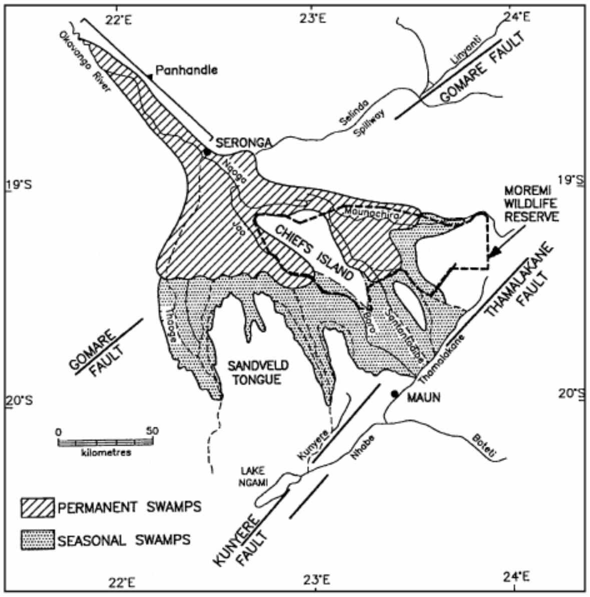

Fig. 1. Map of the Okavango Delta in northwest Botswana, showing the approximate location of the permanent and seasonal swamps. The Harry Oppenheimer Okavango Research Centre field site is located at the southern tip of Chief's Island within the seasonal swamps and adjacent to the Boro River.

October) of 1997.

The soil samples were air dried and passed through a 2-mm sieve. Soil pH was determined in a 1:2 soil: water suspension,[9] and then measured using a Corning pH meter electrode (model 215). Exchangeable cations were extracted in ammonium acetate as outlined in ref. 9. Magnesium and calcium cations in the extracts were determined by atomic absorption spectrophotometery (Perkin Elmer, type 1100). Potassium and sodium in the extracts were determined by flame emission spectroscopy.[10,11] Available P in the soil samples was determined using the Bray P-1 method.[12,13]

Multivariate analysis of variance (MANOVA) was performed in MINITAB. Post hoc analyses were conducted using the Tukey test. Group separation was based on season (that is, during rains, before floods, and after floods) and vegetation communities.

Table 1. Probability levels for statistical significance for different experimental conditions.

Parameter	*F* value	*P*
Season (flooding regime)	5.61	***
Vegetation communities	5.10	***
Season × vegetation communities	1.08	ns
Season × pH	1.42	ns
Season × P	1.74	ns
Season × K	0.47	ns
Season × Na	1.56	ns
Vegetation × pH	126	***
Vegetation × P	19.3	***
Vegetation × Ca	5.97	***
Vegetation × Mg	10.3	***
Vegetation × K	2.28	ns
Vegetation × Na	1.60	ns

ns, not significant ($P > 0.05$); *** $P < 0.01$. Soil pH, P, Ca and Mg varied significantly with vegetation communities, whereas K and Na did not. pH, P, K and Na did not vary with season within a vegetation community.

Results and discussion

Table 1 summarizes the statistical analysis. MANOVA showed that soil chemical nutrients differed significantly with season (flooding regimes) and vegetation communities. However, the season and vegetation community interaction was not significant. Soil pH, available P, K and Na variations were not significant among seasons; Ca and Mg differed significantly with season. MANOVA between vegetation types, pH, P, Ca and Mg showed significant differences, while K and Na, though variable, were not significantly different throughout the year.

Available P increased from the elevated tertiary floodplain communities (SP-CD) to the lower floodplain communities (AS-LS) (Table 2), with highest amounts recorded in the soil closest to the riverbed. The higher available P in the primary floodplain soil may be attributed to higher vegetation density, moisture and microbial activity as these soils are usually moist and have an O horizon rich in microbial substrates. The phosphates in these soils may originate from both plant debris and floodwater. Apart from the soils of the VN-SS and the CA-SC communities, available P did not differ significantly with season within the other soils, a result which could be attributed to the low mobility of P in soils.

Increases in soil K and Na were observed from the AS-LS (the lowest elevation with reference to the river) to the SP-CD communities (the most elevated above the river) (Table 2). Although the increases were as high as 50% for some of the soils, they were not statistically significant in view of the large variations between replicates. The K and Na in these soils probably originated from ashes arising from the burning of floodplain vegetation both at the water source and within the Okavango Delta. These are in turn transported hydrologically and deposited at the fringes of the water, that is, on the tertiary floodplain. Vegetation fires of both natural and human origin are common in the delta.[14] Potassium and Na are major components of ash and burnt plant debris.[15] The high variations in soil K and Na among replicates within each vegetation community may be attributed to uneven distribution of ashes and burnt plant debris deposited by water and wind.[19]

Overall, there was a general decrease in soil nutrients from the primary floodplains to the secondary floodplains and *Sporobolus* islands. This may be attributed to the high levels of organic matter found in the low-lying primary floodplains as opposed to the low organic matter content of the tertiary floodplains. Organic matter is an important soil constituent, serving as a substrate for microorganisms and also as a reservoir for soil nutrients. Inundation of floodplain vegetation promotes accumulation of organic material, which remains partially undecomposed until the water has receded, and the soil drained. After floods recede, microbial plant decomposition resumes, resulting in the formation of organic matter. At these times, most of the accumulated organic material decomposes and releases nutrients to the soil, thus resulting in high soil fertility in the primary floodplains.

The effect of flooding on soil K and Na in the different vegetation communities varied with the community. Significantly higher K and Na contents were observed in the SP-CD areas after floods. Apart

Table 2. Multiple comparisons of overall means of different conditions in the vegetation zones.

Community type	pH	P	K	Mg	Ca	Na
Alternanthera sessilis – Ludwigia stolonifera	5.45^{a}	20.52^{a}	145	315^{d}	1755^{b}	52
Cyperusarticulatus – Schoenoplectus corymbosus	5.68^{a}	7.21^{a}	166	287^{cd}	1389^{ab}	65
Miscunthus junceus – Digitaria scalarum	5.84^{a}	11.52^{a}	148	182^{b}	1128^{ab}	23
Paspalidium obtusifolium – Panicum repens	5.98^{a}	5.51^{a}	127	$217b^{c}$	936^{ab}	18
Eragrostis inamoena – Setaria sphacelata	6.10^{a}	5.40^{a}	120	134^{b}	708^{a}	16
Imperata cylindrica – Setaria sphacelata	6.88^{b}	4.53^{a}	228	187^{b}	1234^{ab}	5
Veteveria nigritiana – Setaria sphacelata	6.49^{b}	5.78^{a}	139	181^{b}	625^{b}	12
Sporobolus spicatus – Cynodon dactylon	8.88^{c}	3.46^{b}	335	30^{a}	903^{ab}	466

Means followed by the same letter are not statistically different from each other at $P < 0.05$.
*Cation concentrations in ppm.

from these soils, the effect of flooding on K and Na content was generally not significant in other soils. In the primary and secondary floodplains, soil K was always low before the inundation and increased afterwards, an indication that potassium may be deposited by floodwaters. High K content was observed during the rainy season, but declined in the dry season and then increased after the floods. The high fluctuations in soil Na in the different vegetation zones could also be associated with burning upstream; the sediment is heavily loaded with Na, a major cation in ashes. If these variations in Na were of parent material origin, the fluctuations would not be 100-fold as observed. Low levels of Na after floods may also be a result of leaching, since Na salts are highly soluble.[16] Potassium salts are also highly soluble in water, resulting in low levels in the soils before floods, also as a result of leaching from soils during the rain season.

The soil Ca and Mg contents differed significantly between vegetation communities and seasons ($P < 0.001$). Overall, the Mg and Ca contents decreased from the primary floodplains (AS-LS, CA-SC-communities) to the secondary floodplains (PO-PR, SS-EI, IC-SS and VN-SS) and island grasslands (SP-CD). However, the influence of flooding within the vegetation communities differed with the community. Significant higher soil Ca contents were observed in the rainy season in all but the highest elevated vegetation community (SP-CD). Levels of extractable Ca were also highest in vegetation communities closest to the river bed. However, inconsistently higher soil Mg was observed after the floods in the different vegetation communities (Table 3). Highest levels of Mg were recorded after floods, whereas the highest levels of soil Ca were recorded during the rainy season. The differences in Mg and Ca concentrations between and within the different vegetation zones and over the seasons may also be attributed to the role that wind and water play in the transportation of salts containing these elements.[19] The Ca and Mg additions to these soils are probably of aerial origin.[19] In this case, they may be sourced from the Makgakgadi pans to the east. These salts are then deposited by rain into the river, thus resulting in higher Ca and Mg values in vegetation communities closest to the Boro.

Despite the higher Mg and Ca content of the primary floodplain soils, soil pH (Table 2) decreased from the tertiary floodplains to the river (primary) communities, indicating the possible influence of aluminium and iron cations, as the soils underneath the islands are characterized by relatively high values of aluminium and iron.[18] In this study, Ca was the most abundant extractable cation in soil followed by Mg, K and Na (Table 2). The low extractable Na content and low pH indicate that, although these soils are located in a semi-arid region, they are not saline.

Conclusion

These results indicate that the distribution of soil macronutrients in the surface horizon of the different vegetation zones of the Okavango Delta is not uniform. Available P, Ca, and Mg levels decrease with distance from the riverbed, whereas pH, K and Na contents increased. Soil nutrient content in the different vegetation communities varied with location from the river and also with season. The dominance of extractable cations decreased in order from Ca, Mg, K to Na. These data also indicated that, unlike many wetlands dependent on precipitation, the Okavango Delta, which relies on surface flow for replenishment of water, has high levels of soil cations.

1. McCarthy T.S., Ellery W.N. and Ellery K. (1993). Vegetation induced subsurface precipitation of carbonate as an aggregation process in the permanent swamps of the Okavango (Delta) fan, Botswana. *Chem. Geol.* **107**, 111–131.
2. McCarthy T.S., Stainstreet I.G. and Caincross B. (1991). The sedimentary dynamics of active fluvial channels on the Okavango fan, Botswana. *Sedimentology* **38**, 471–487.
3. Mitsch W.J. and Gosselink J.G. (1993). In *Wetlands*, chap. 10, pp. 722–843. Van Nostrand Reinhold, New York.
4. Biggs R.C. (1979). *The ecology of Chief's Island and*

Table 3. Soil macronutrient composition (in ppm) in different vegetation communities and seasons.

	Season			
Community type	Rainy season	Before floods	After floods	Annual mean value
Alternanthera sessilis — Ludwigia stolonifera				
pH	5.28	5.69	8.50	5.45
P	13	19	21	21
Ca	2072	1549	1645	145
K	147	111	177	315
Mg	315	186	286	1755
Na	71	54	23	
52				
Cyperus artuculatus — Schoenoplectus corymbosus				
pH	5.47	5.56	6.02	5.68
P	10	9	3	7
Ca	1910	1046	1211	166
K	188	102	209	287
Mg	287	127	210	1389
Na	51	17	129	65
Miscunthus junceus — Digitaria scalarum				
pH	5.63	5.82	6.05	5.84
P	10	13	12	12
Ca	1258	1052	1074	148
K	162	137	146	182
Mg	183	148	172	1128
Na	34	24	11	23
Paspalidium obtusifolium – Panicum repens				
pH	5.98	6.07	5.89	5.98
P	6	5	6	6
Ca	1495	693	621	127
K	170	80	130	217
Mg	217	80	119	936
Na	25	23	10	18
Eragrostis inamoena – Setaria sphacelata				
pH	6.29	5.82	6.18	6.10
P	7	5	4	5
Ca	807	650	667	120
K	125	80	157	134
Mg	134	85	134	708
Na	27	4	14	16
Imperata cylindrica – Setaria sphacelata				
pH	7.03	6.85	6.76	6.88
P	6	5	5	5
Ca	1568	1215	919	228
K	142	381	160	187
Mg	187	91	152	1234
Na	11	5	0	5
Veteveria nigritiana – Setaria sphacelata				
pH	6.25	6.46	6.57	6.49
P	8	3	6	6
Ca	988	379	508	139
K	203	76	138	181
Mg	181	66	100	625
Na	21	5	12	12
Sporobolus spicatus – Cynodon dactylon				
pH	9.04	8.78	8.75	8.88
P	5	3	3	3
Ca	870	898	942	335
K	213	319	526	30
Mg	30	27	29	903
Na	30	281	1087	466

the adjacent floodplains of the Okavango Delta, Botswana. M.Sc. thesis, University of Pretoria.
5. Ellery K. and Ellery W. (1997). In *Plants of the Okavango. A field guide,* pp. 6–9. Tsaro Publishers, Durban.
6. Bonyongo M.C. (1999). *Vegetation ecology of the seasonal floodplains in the Okavango Delta, Botswana.* M.Sc. thesis, University of Pretoria.
7. Snow Mountain Engineering Company (1986). A profile for environment and development in Botswana. Ministry of Local Government and Lands, Ngamiland District Land Use Planning Unit. Government of Botswana, Gaborone.
8. Staring G.J. (1978). In *Soils of the Okavango Delta,* pp 68-79. UNESCO, Gaborone.
9. Maclean E.O. (1982). Soil pH and lime requirements. In *Methods of Soil Analysis. Part 2: Chemical and Microbiological Properties,* eds A.L. Page, R.H. Miller and D.R. Keeney, pp. 199–224. American Society for Agronomy, Madison, WI.
10. Anderson J.M. and Ingram J.S.I. (1989). In *Tropical Soil Biology and Fertility: A handbook of methods,* pp. 59–62. CAB International, Wallingford, Oxon.
11. Thomas W.G. (1982). Exchangeable cations. In *Methods of Soil Analysis. Part 2: Chemical and Microbiological Properties,* eds A.L. Page, R.H. Miller and D.R. Keeney, pp. 159–162. American Society for Agronomy, Madison, WI.
12. Bray R.H. and Kurtz L.T. (1954). Determination of total organic and available forms of phosphorus in soils. *Soil Sci.* **59**, 39–45
13. Olsen S.R. and Sommers L.E. (1982). Phosphorus. In *Methods of Soil Analysis. Part 2: Chemical and Microbiological Properties,* eds A.L. Page, R.H. Miller and D.R. Keeney, pp. 416–418. American Society for Agronomy, Madison, WI.
14. Heinl M. (2001). *Fire and its effects on vegetation in the Okavango Delta,* M.Sc. thesis, Technical University of Munich, Munich.
15. Mengel K. and Kirkby E.A. (1982). *Principles of Plant Nutrition.* International Potash Institute, Berne.
16. Brady N.C. (1990). *The Nature and Properties of Soils.* Macmillan, New York.
17. Khresat S.A., Rawajfih Z. and Mohamad M. (1998). Morphological, physiological and chemical properties of selected soils in the arid and semi-arid region in northwestern Jordan. *J. Arid Environ.* **40**, 15–25.
18. McCarthy T.S., Ellery W.N. and Dangerfield J.M. (1998). The role of biota in the initiation and growth of islands on the floodplain of the Okavango alluvial fan, Botswana. *Earth Surf. Proc. Landf.* **23**, 291–316.
19. Garstang M., Ellery W.N., McCarthy T.S., Scholes M.C., Scholes R.J., Swap R.J. and Tyson P.D. (1998). The contribution of aerosol and water-borne nutrients to the functioning of the Okavango Delta ecosystem, Botswana. *S. Afr. J. Sci.* **94**, 223–229.