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Full Length Research Paper

Analysis of persistence soil nutrient status in abandoned cattle kraals in a semi arid area in Botswana

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The aim of this study was to analyze the depletion of soil nutrients with time on abandoned kraals in a peri-urban area of Botswana. Active kraals are enriched with nutrients through the accumulation of animal droppings and this study was aimed at assessing how long the impact of this soil nutrient enrichment persists after kraal abandonment. A total of 25 disused kraals, that had been abandoned for periods ranging from 1 to 45 years were sampled. The soil parameters analyzed included particle size distribution (%), bulk density (g/cm^3), pore space (%), moisture content (%), pH in water and KCl solution, EC (µS/cm), organic matter (%), CEC (meq/100g), exchangeable Ca^{++}(cmol$_c$/kg), Mg^{++}(cmol$_c$/kg), K^+(cmol$_c$/kg), Na^+ (cmol$_c$/kg), nitrogen [NH_4-N (mg/kg), NO_3-N (mg/kg), TKN (%), and Olsen P (mg/kg). Results showed that soil nutrient concentrations on abandoned kraals generally were significantly higher than at the control sites. Soil nutrient concentrations decreased with time as abandoned kraals retrogressed towards their pre-kraal conditions. However, the effects of soil nutrient enrichment from animal wastes persist long after kraal abandonment. For example, soil Olsen P, Ca^{++} and Mg^{++} levels in kraal sites that had been abandoned for over 45 years were still significantly higher than in the control sites. In a pastoral system such as is practiced in Botswana where kraal manure is not used as soil amendment, the whole ecosystem suffers as soil nutrients are transferred and concentrated at isolated spots (kraals).

Key words: Abandoned kraal, soil nutrient status, pastoral systems, semi-arid.

INTRODUCTION

Kraaling has always characterized pastoralism in semi-arid environments and up to this day, kraaling is still widely practiced as an important aspect of the extensive livestock management system in many developing countries. However, evidence from various studies have shown that a growing population (Jagtap and Amissah-Arthur, 1999) and modern developmental challenges (Tiffen, 2006; Kangalawe et al., 2008) have created a shift in the historically extensive livestock management systems. As the area of available land becomes limited, grazing lands are being taken up by residences and industrial land use. This has caused profound changes such that grazing lands and kraal areas are increasingly being abandoned. The abandoned kraals have thus gradually become more common features in urban and peri-urban built up areas. Because kraaling is mainly for the security of livestock among other factors, kraal owners rarely consider the long-term implications of the kraals on the soil environment particularly after the kraals are abandoned.

Livestock management by the use of kraals exerts an influence on soil nutrients (Stelfox, 1986; Augustine, 2003). Dung and urine deposited in the kraal area contain plant nutrients harvested by livestock from the surrounding grazing area(s) centripetally transported towards the kraal area. Kraals are thus concentrated with nutrients in comparison to their surrounding areas particularly in arid and semi-arid environments (Schwiede et al., 2005), making them unique and important in these areas. The high nutrient concentrations within the smaller area of a kraal located within the wider landscape affects the soil chemistry and accentuates spatial imbalances in soil nutrient distribution in the grazing lands (Muchiru et al., 2008). This is more likely to be so in pastoral systems like Botswana's where kraal manure is not harvested,

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recycled or effectively utilized. This poses a risk to the general environmental quality because it alters the pattern of nutrient cycling and consequently causes instability in the ecosystem. The main focus of this study is the persistence of the spatial imbalance in soil nutrient distribution created by the transfer and concentration of nutrients in kraals after the kraals have been abandoned and gone into disuse. The aim of this paper, therefore, is to make a comparative analysis of soil nutrient and quality parameters between disused kraals that had been abandoned for different lengths of time. This is to be able to analyze the decline in soil nutrient levels with length of kraal abandonment and determine the length of time it takes for the impact of nutrient accumulation in the kraals on soil nutrient imbalances to dissipate. The findings would have implications for the recycling of kraal nutrients and for the management of soil nutrients particularly in a semi arid environment such as Botswana. The results should contribute to information on agricultural development and sustainability considering the challenge of the inherently low soil nutrient status in these areas.

This study was carried in Tlokweng village a peri-urban area of Gaborone, the capital city of Botswana in southern Africa. At the time Botswana became an independent republic in 1966, Tlokweng village was a rural area characterized by cattle posts and arable fields (lands). But, over the last four decades and more, Gaborone, the capital city of Botswana, has expanded rapidly into Tlokweng village. The latter, like many other peri-urban areas in developing countries now contains a unique mix of traditional livestock keeping and arable farming in a rapidly urbanizing environment (Gwebu, 2006). Tlokweng village is representative of those areas in Botswana where traditional livestock keeping had been an important source of livelihood for centuries but where rapid urbanization and other economic and socio-cultural factors have increasingly led to the abandonment of arable and grazing lands and the associated homesteads and kraals. Land speculation by both urban and rural dwellers has increased the pace of encroachment of built up areas into former arable and grazing lands.

STUDY AREA

Tlokweng Village is located east of Gaborone in the South East district of Botswana (Figure 1). The area has a semi-arid climate that is characterized by marginal (525 mm/year) and erratic (23% CV) rainfall most of which falls during the summer period between November and March. Mean temperatures range between 25°C and 35°C in summer and 3°C and 11°C in winter. With the exception of areas of rock outcrops, the area is generally flat or gently undulating with 0.2 to 0.5% slopes. The area lies generally between 960 and 1200 m above sea level. Although the area is generally flat, there are several seasonally flowing channels that drain into the Notwane River. The present landscape is the result of past fluvial activity and continuing weathering processes. Gaborone granite is the major lithological complex underlying the area covering approximately 80% of the area. Sedimentary deposits are mainly sandstones which tend to overlay granitic bedrock. Decomposed granite is the main component constituting the unconsolidated material.

The soils were derived from granitic parent materials and they are generally coarse – textured, with clay enriched subsoils due to downward eluviation of clay minerals in the soil profile. The soils are dominated by arenosols and weakly developed luvisols that are interrupted by vertisols in riparian corridors (SMASP, 2006). There are no recorded or known mining related activities in the area. Vegetation has been described as tree and shrub savanna (Skarpe, 1991). Arable farming has substantially declined because of persistent rainfall failures that have forced farmers to shift emphasis from crop to livestock production. This trend has narrowed livelihood options for most farmers with increased dependence on cattle rearing and persistent increase in livestock numbers stressing the area's grazing resources to the extent that rangeland degradation has become one of the village's major problem issues. This problem is aggravated by the expansion of Gaborone city into traditional grazing areas.

METHODS

Inventory of abandoned Kraals

Abandoned kraals are defined as those that are no longer actively utilized by livestock and which have been abandoned for a minimum of 2 years. In order to make an inventory of abandoned kraals in the Tlokweng, interviews were first conducted with key informants comprising village elders above 60 years of age, extension workers and livestock herders. Elderly people were targeted because they were reasoned to be capable of remembering locations of long-abandoned kraals while extension workers and herders were expected to be knowledgeable about those that had been recently abandoned because of their use during animal vaccination campaigns and for overnight protection. These interviews were then followed up with extensive field reconnaissance to identify the abandoned kraal locations. Vegetation was used as the indicator for identifying former kraal sites. Both the vegetation structure and the underlying soils often manifest the localized concentration of animal dung and urine for which kraal are noted. Altogether, 36 abandoned kraals were identified out of which 25 were selected for sampling. The 25 abandoned kraals were classified into 5 groups based on the length of time since abandonment as shown in Table 1. There were more recently abandoned kraals than older ones, hence the variation in class intervals used in the grouping. In addition to the selected abandoned kraals, 5 sites were chosen outside the kraal sites to serve as controls. These sites were located within the same vegetation unit and covered by the same highly sandy soils (Arenosols) as in the kraal sites.

Soil sampling

Soil sampling was done during the dry season which was found conducive for field work. Soil sampling was done at five randomly located points within each abandoned kraal and in the control sites. The soils were sampled at two depths, 0 to 15 cm, 15 to 35 cm, using mini-soil pits dug at each sampling point. The soil samples were air dried in the laboratory and sieved through a 2 mm sieve for different types of laboratory analyses.

Soil analysis

The soil samples were analyzed for particle size distribution, bulk Density (g/cm^3), pore space (%), moisture content (%), pH in water

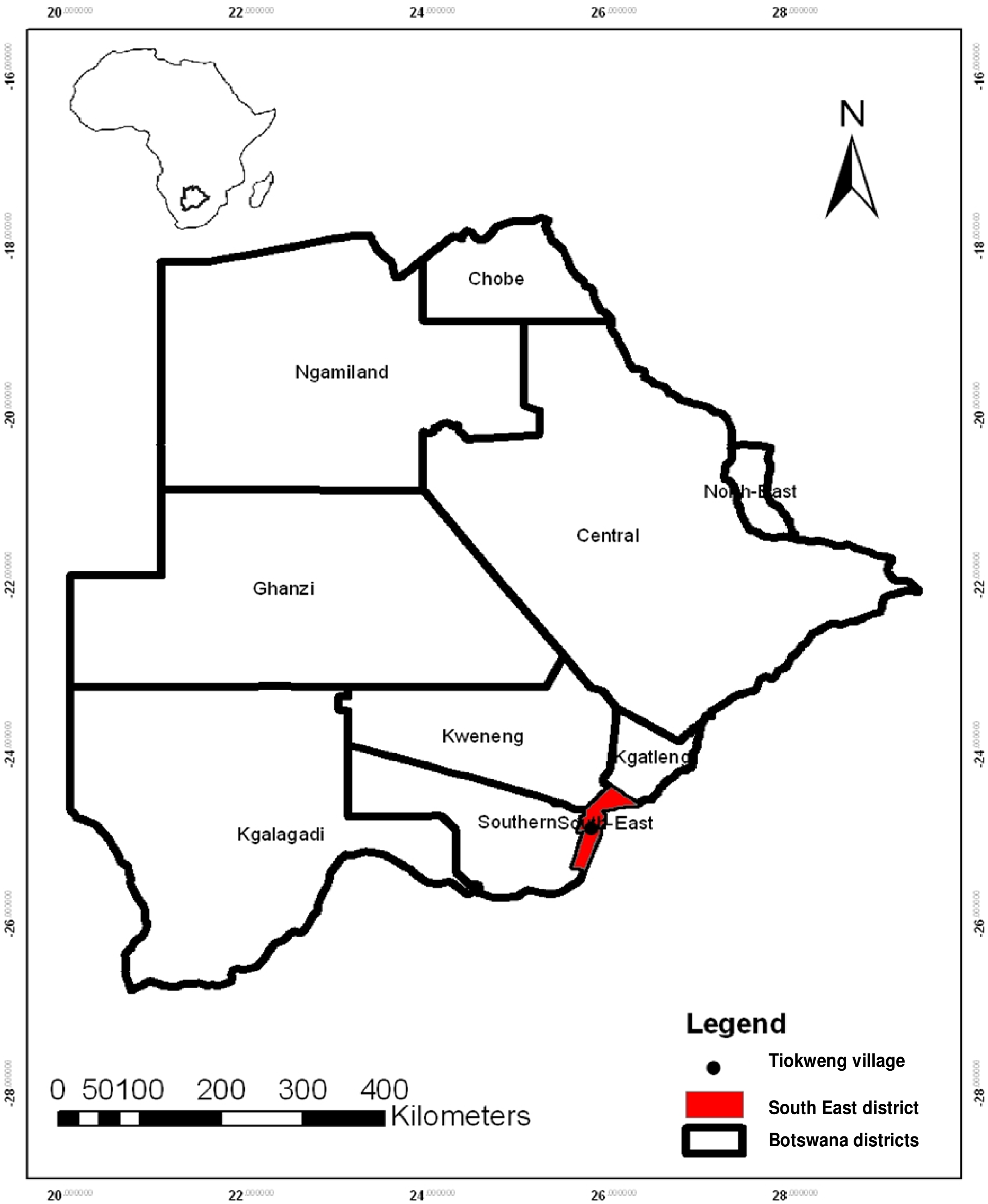

Figure 1. Location of Tlokweng village in the South East district of Botswana.

Table 1. Abandoned kraals investigated and length of time after kraal abandonment.

Length of time after kraal abandonment (years)	No. of sites for each kraal category
< 5	5
6 -10	5
11 – 20	5
21 – 40	5
> 45	5

Table 2. Summary of analytical methods applied for soil analyses.

Soil parameters	Analytical methods
pH	Potential determination in both water and KCl suspensions (Van Reeuwijk, 2006; Okalebo et al., 1993)
Moisture content	Gravimetric analysis of moisture content of the difference in weight before and after oven drying of sample (van Reeuwijk, 2006)
Electrical conductivity (EC)	Saturation paste and a subsequent vacuum extraction of the liquid phase (USDA, 1995)
Bulk density (D_b) and % Pore space	Oven dry weight of a sample to determine D_b (Tan, 1996) D_b value above was used to determine % pore space (Okalebo et al., 1993)
Particle Size Distribution (PSD) and textural classes	Pre-treatment of samples to destroy their binding components and consequent dispersion into their primary particles (USDA, 1996) Texture Autolookup Software Package (TAL Version 4.2) (2002) to determine textural classes
Cation Exchange Capacity (CEC)	Ammonium acetate (CH_3COONH_4) extraction technique (USDA, 1995)
Organic Matter (OM)	A modified Walkely-Black wet combustion method for organic carbon determination (USDA, 1996; van Reeuwijk, 2006)
Olsen Phosphorous (P)	The Olsen et al.(1954) phosphorous extraction technique (USDA, 1995)
Ammonium Nitrate, (NH_4^+-N) Nitrate Nitrogen (NO_3-N)] Total Kjeldahl Nitrogen (TKN)	Available N from individual samples was obtained according to extraction procedure developed in Okalebo et al. (1993) Extractiable NH_4^+-N and NO_3-N from the extracted available N extracts was determined by distillation and titration procedures TKN was determined by a modified Kjeldahl wet acid oxidation of the sample followed by distillation and titration procedures (Okalebo et al., 1993)
Exchangeable bases (Exch. Ca, Mg, K, Na)	Ammonium acetate (CH_3COONH_4) extraction technique (van Reeuwijk, 2006; USDA, 1995) was used to extract the exchangeable bases from the soil samples Flame Atomic Absorption Spectrometer (FAAS) was used to determine Ca^{2+} and Mg^{2+} Flame Photometer was used to determine Na^+ and K^+

and potassium chloride solution, EC (µS/cm), organic matter (%), CEC (meq/100g), exchangeable bases Ca^{++}($cmol_c$/kg), Mg^{++}($cmol_c$/kg), K^+($cmol_c$/kg), Na^+ ($cmol_c$/kg), nitrogen (NH_4-N (mg/kg), NO_3-N (mg/kg), TKN (%) and Olsen P (mg/kg). Analysis of the properties was based on standard laboratory techniques of soil analyses as described by Van Reeuwijk (2006); Tan (1996); Okalebo et al. (1993) and USDA (1995; 1996). The analytical methods applied for the different soil parameter are indicated in Table 2.

Data analyses

Analytical data on the soils of the abandoned kraal and control sites are tabulated in Table 2. The means, variance and standard deviations of values for each parameter for each group of

Table 3. Analytical soil data on abandoned cattle kraals and control sites.

	Control site	Sample average values by duration of abandoned kraals				
Soil parameters	**Values**	**<5 years**	**10 years**	**20 years**	**30 years**	**>45 years**
pH-H_2O[a]	5.5	8.2*	8.0*	7.8*	7.5	7.2*
pH-KCl[a]	5.3	7.1	7.4	7.0	6.7	6.6
CEC (meq/100g)[a]	2.4	3.8	3.7*	3.7	3.6	3.6
OM (%)[a]	0.7	1.4*	1.3*	1.2	1.2	1.1*
Pore space (%)[a]	42.1	48.5	47.7	43.2	41.4	40.2
Moisture content (%)[b]	1.2	2.5	2.3	2.2	2.3	2.0
Bulk density (g/cm^3)[d]	1.5	1.5	1.1	1.5	1.5	1.4
EC (µS/cm)[a]	18.5	31.0*	120.0*	120.0*	90	40
Olsen P (mg/kg)[c]	0.7	20.0*	18.3*	19.6	20.0	20.1*
Exch. K ($cmol_c$/kg)[a]	1.3	7.5*	7.5*	7.3*	7.1	7.1
Exch. Na ($cmol_c$/kg)[a]	0.2	0.4	0.4	0.3*	0.3	0.3
Exch. Ca ($cmol_c$/kg)[a]	3.0	9.0*	8.6*	8.5*	8.1	7.5*
Exch. Mg ($cmol_c$/kg)[a]	0.9	2.7	2.6*	2.6*	2.5	2.4
NH_4-N (mg/kg) [b]	98.9	114.5	100.0*	100.0*	98.8*	98.8
NO_3-N (mg/kg)[b]	100.0	120.0	100.0	98.9	100.0	100.0
TKN (%)[d]	0.1	0.4*	0.3	0.2	0.2	0.2
Sand	75.8	69.7	72.1	72.1	74.1	73.2
Silt	13.4	19.9	14.4	14.4	16.5	15.5
Clay	10.8	10.4	13.5	13.5	9.4	11.5
Texture[d]	SL	SL	SL	SL	SL	SL
Number of samples	**5**	**5**	**5**	**5**	**5**	**5**

*Significant at p = 0.05, SL = Sandy loam, a = Persistent decrease, b = initial increase and terminal stabilization, c = initial decrease and terminal increase, d = stable trends.

abandoned kraals were calculated. Comparison between abandoned kraals of different duration was done on the basis of these individual soil parameters using both the Student's t-test and the analysis of variance (ANOVA). The Statistical Package for Social Scientists (©SPSS Inc. Version 17, 2009) and Microsoft Office Excel (Microsoft® Office 2007) were used to run all calculations with levels of significance being determined at the 95% confidence limit.

RESULTS

Table 3 shows a summary of the soil data for both control sites and abandoned cattle kraals while Figure 2 displays general temporal trends of various soil parameters at the kraals. It is important to note that all the soils are similar in terms of particle size distribution (ANOVA, $P = 0.05$; $\sigma = \pm 0.4$) and they all belong in the same textural class, sandy loam. Understandably, bulk density values, which are highly dependent on soil texture, are also comparable on all sites. Thus, any differences seen in the other soil parameters between various abandoned kraal groups can reasonably be attributed to differences in length of abandonment. In general, with the exception of TKN, soil nutrient concentrations are lower in the control sites ($P = 0.05$) than in the abandoned kraal areas. Indeed, the >45-year abandoned kraals have much higher soil quality parameters than the control site soils ($t = 0.05$) suggesting a long term persistence of the impact of organic waste accumulation in the kraals.

Abandoned kraals of less than 10 years have slightly alkaline soils (example, pH - H_2O 8.0 and pH-KCl 7.4 at 10 years), while soil pH values have declined to near neutral (example, pH-H_2O 7.2 and pH-KCl 6.6 at >45 years) on those kraal sites that had been abandoned for longer periods. Control site soils are all slightly acidic in reaction with average pH-H_2O of 5.5 and pH-KCl of 5.3. There is a progressive decline in CEC, OM%, K^+, Na^+, Ca^{++}, Mg^{++}, NH_4-N and NO_3-N with length of time after kraal abandonment (Figure 2). A similar trend is also true of pore space indicating that the soils become less compacted and more structured as the length of kraal abandonment increase. However, some parameter sinitially increase in level in the early period of abandonment up to about 10 years before there is a reversal to a downward trend. Such parameters include moisture content (%), EC (µS/cm), NH_4-N (mg/kg) and NO_3-N (mg/kg) whose concentration levels appear to peak at 10 or 20 years. The initial increase may be as a result of the thorough humification of the accumulated organic wastes into soil organic matter with its positive impact on soil properties. But, the subsequent oxidization of the soil organic matter content must have led to the decline experienced after 10 or 20 years in these dependent soil parameters. In contrast, Olsen P (mg/kg) exhibited

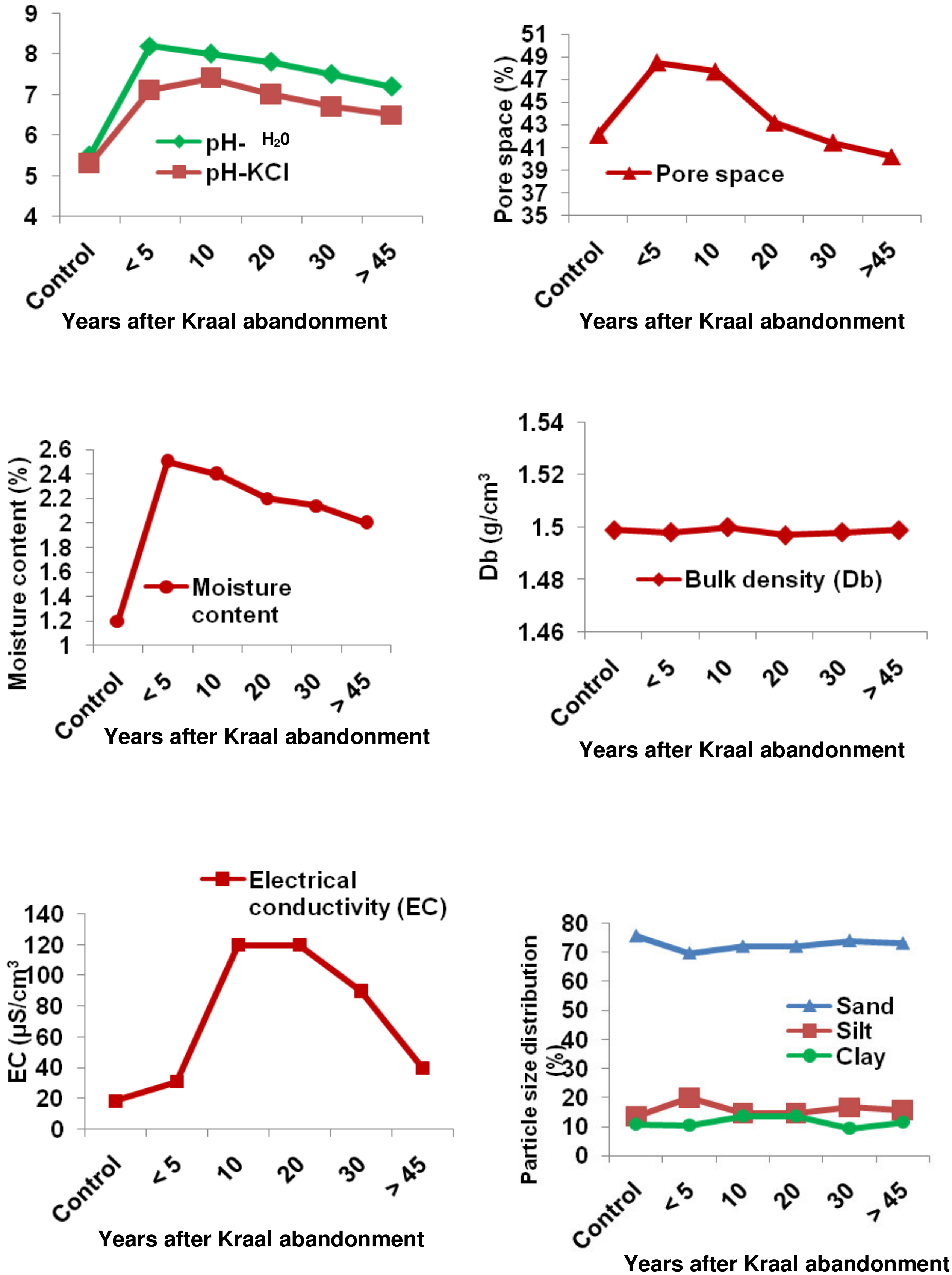

Figure 2. Temporal trends of soil parameters at abandoned kraals.

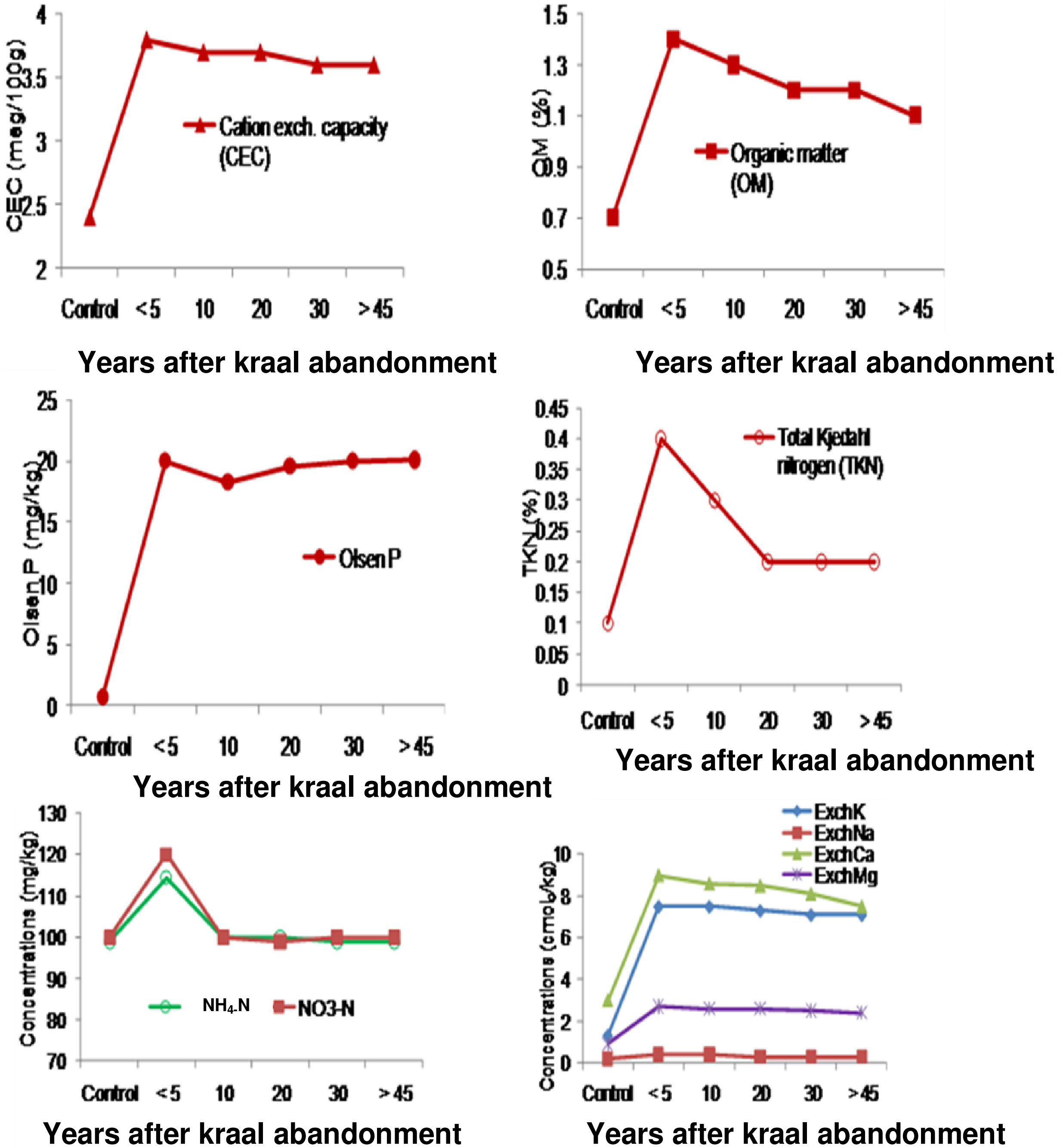

Figure 2. Contd.

an initial decline up to about year 10 and then it rises steadily to reach its highest level in abandoned kraals of over 45 years.

DISCUSION

The dominant soil textural class at kraal sites and their surroundings (control) is consistent with the geology of the study area since textural properties are determined by the soil parent materials. The similarity in particle size distribution at both abandoned kraal sites and the control shows that the soils were formed from quartz-rich regolith. It also suggests that the kraal soils which are clay deficient derive their nutrients largely from animal wastes and plant litter.

The textural homogeneity of soils in the study area also makes the comparative analysis of soil quality parameters between the abandoned kraal sites and the control sites relatively easy. The fact that soil conditions in abandoned kraal sites of over 45year are significantly better than on the control sites shows that the impact of the organic waste accumulation in kraals persists for a long time even after kraal went into disuse. The persistence of nutrient-rich patches coinciding with the abandoned kraal sites for such a long period is indicative of induced obstruction to nutrient circulation which increases the patchiness of semi-arid ecosystems. This phenomenon suggests that delayed re-establishment of initial soil conditions after the abandonment of kraals can have co-extensive adverse effects on productivity as localized accumulation of manure is a result of nutrients that are being mined and transferred from the surrounding source areas.

Accumulation in the soil of the negatively charged OM with high surface charge density (Brady and Weil, 2002) accounts for above-neutral pH, high EC, elevated levels of CEC and the substantially high soil nutrient status of kraals compared to their surroundings. Exposure to persistent leaching and related processes of OM mineralisation (Hansson et al., 2010) induce sustained loss of nutrients over time with numerous driver combinations accounting for kraal-type imbalances in nutrient concentrations. As abandoned kraals advance in age, the mineralisation of OM enhances nutrient loss and long-term decrease in soil nutrient levels while the long-term decrease in exchangeable bases corresponds to similar trends in OM content that reflect the greatly reduced intensity of dung and urine additions following the abandonment of individual kraals. But, as depicted in the present study, the rate of loss or decline in soil nutrients is relatively slow; indeed, as indicated above, some elements of soil quality actually improve significantly in the first 10 to 20 years following abandonment of a kraal.

Decrease in pore space with increase in duration of abandonment is explained by related trends in bulk density owing to trampling within and around kraals while the decrease in EC reflects the influence of increased infiltration as porosity increased (Barzegar et al., 2002). With less effect of trampling and hoof action of cattle at abandoned kraals, soils tend to loosen up thereby reducing soil bulk density which in turn improves water infiltration rates, and microbial activity and, invariably, promotes more release of nutrients.

The deviation of Olsen P from the general pattern of declining status with age of abandoned kraals (Table 2) can be explained by its highly reactive nature at different levels of acidity to form stable compounds (Hao et al., 2004; Jiao et al., 2007). Olsen P requires a pH between 6.0 and 7.0 and becomes chemically immobile outside this range, forming insoluble compounds with Fe and Al and Ca (Jiao et al., 2007). High levels of Ca in dung derived from the leguminous plants that are rich in this nutrient provide a plausible explanation of high dry-season concentrations of Olsen P elevated by immobilisation and compounding of P with Ca when leaching from rainfall is absent. Spatial disparities in amounts of P can be attributed to differences in quantities of OM and concomitant variations in the magnitude of mineralisation. P in the young manure of abandoned kraal largely occurs in an organic form that is only available for plant uptake and leaching after mineralisation (Chardon et al., 2007). Because manure stores P in organic form (Brady and Weil, 2002), this storage provides a possible explanation of the spatial disparities in its distribution on account of its assimilation to OM of similarly varied distribution.

High concentrations of exchangeable K and exchangeable Ca in comparison with other exchangeable bases point to the possible influence of mineralogy (that is, composition of soil-forming rocks) and complex chemical activities. The former is likely to be substantial in this environment due to the prevalence of feldspars and micas (Ekosse et al., 2006). Since bases in these minerals are largely immobile and not readily extractable by plants (Brady and Weil, 2002), levels of exchangeable K are high and further elevated by the prevalence of leguminous acacias in this environment (Ringrose and Matheson, 1991; Skarpe, 1991). Because these species are rich in exchangeable bases, notably Ca, K and Mg (Lauren et al., 2001), and are widely browsed by cattle (Moleele et al., 2002), cow dung augments immobile storages by providing substantial amounts of externally sourced K.

The declining pattern of soil NH_4-N, NO_3-N and stable levels of TKN through time could be attributed to a decrease in the rates of organic waste mineralization when kraals are abandoned. This explains the elevated nutrient levels and hence higher soil nutrient status in young abandoned kraals (<10 years) when compared with old abandoned ones (>45 years). The temporal variations in the observed soil NH_4-N and NO_3-N levels are in agreement with findings from similar semi-arid areas where cattle kraals are widely used for livestock management (Hiernaux et al., 1998; Yousif and Abdalla, 2009). Although these similarities are typical of trends in most semi-arid grazing lands, deviations have also been reported from lower rainfall areas of the Kalahari indicating no observable differences in the concentrations of NH_4-N and NO_3-N over periods of comparable duration (Dougill and Cox, 1995). These differences are indicative of higher rates of volatilisation and leaching in the study area because of rainfall amounts slightly in excess of the Kalahari's marginal amounts. This influence of rainfall on nutrient fluxes suggests that differences in a narrow range of vital attributes can induce divergent trends irrespective of broad similarities in the majority of key determinants. This observation is important because it shows the extent to which marginal rainfall in semi-arid areas may facilitate nutrient retention by undermining the translocation of nutrients. The important insight from these observations is that in areas with marginal rainfall, accumulation of manure in cattle kraals can disrupt nutrient balances by facilitating the translocation of nutrients in the form of dissolved and suspended load in surface flows generated by short-lived seasonal outbursts of heavy rainfall. This proposition is supported by long-term decrease in the concentration of nutrients for samples that were extracted from the abandoned cattle kraals (Table 3). The progressive loss in soil nutrients over time after kraals are abandoned however show that despite the persistence of the nutrient enriched patches, kraal soils would ultimately revert to their original nature determined primarily by the parent materials. The same declining trend further suggests that management strategies that enhance nutrient accumulation can have adverse ecological effects by shortening and disrupting natural pathways of nutrient circulation.

Conclusion

This study has shown that organic waste accumulations in kraal areas greatly enhance the nutrient status of these naturally nutrient deficient sandy soils. The organic wastes also result in marked improvements in the physical and moisture conditions of the sandy soils. However, the nutrients generated from the organic wastes do not accumulate in the soil indefinitely but decline over time after kraal abandonment. The rate of decline appears to be slow such that soils in kraals that have been abandoned for over 45 years still manifest the impact of the organic waste accumulations. Non use of manure in arable farming is a common phenomenon in arid and semi areas. Therefore, cattle manure does not provide a readily accessible source of organic material for soil amendment. This study has highlighted the great loss that this constitutes to the semi-arid ecosystem and the promotion of soil productivity. There is need to modify age-old traditional livestock management practices in a country such as Botswana that is pursuing a policy of food self-sufficiency and security, so that kraals can be harvested as ready sources of organic manure for soil amendment.

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