Soil chemical changes following 3-year legume or grass leys in west Africa

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Abstract

The influence of 4 tropical grasses [*Panicum maximum*, *Andropogon gayanus* broad- (BL) and narrow-leaf (NL) types and *Pennisetum purpureum*] and 6 legumes (*Aeschynomene histrix*, *Stylosanthes fruticosa*, *Centrosema pubescens*, *Mucuna pruriens* var. *utilis*, *Cajanus cajan* and *Leucaena leucocephala*) on fertility of the topsoil in the Sudanian region of Benin over 3 years was investigated. The plants were sown without fertiliser, harvested under a cut-and-carry regime and soil changes were compared with those under a natural fallow. Soil samples were collected before the study commenced and at the end of the 3-year study. These were analysed for pH, organic C, N, available P and exchangeable cations (Ca, Mg, K and Na). N, P and K contents of aerial parts were determined to estimate the exports of these elements. For the grasses, root biomass, depth and distribution were also measured. Three years after grasses and legumes were sown, the pH under the grasses (6.6–6.7) was higher than under the legumes (6.2–6.3) and C and N concentrations had declined from the initial levels. Owing to their deep rooting systems, *A. gayanus* BL and *P. maximum*, and probably *C. cajan* and *L. leucocephala*, appeared able to recycle nutrients from deeper soil layers. While these species could be

used for ley pastures in savannah regions of west Africa, maintenance fertiliser applications would be required to prevent nutrient depletion under a cut-and-carry regime. Further studies to test the efficacy of farmyard manure in providing these nutrients and to examine the growth of the legumes when inoculated with appropriate rhizobia seem warranted.

Introduction

In most regions of west Africa, the land is under increasing pressure as farmers attempt to improve their livelihoods using extensive techniques, based solely on what the soil can produce naturally. Low soil fertility constitutes a real constraint to crop yields (Soumaré *et al.* 2002; Saidou 2006; Somé *et al*. 2007) as fallow periods used to regenerate soils are reduced, limiting their ability to restore fertility in traditional farming systems (Rethman 2000; Koutika *et al*. 2002; Nikiema 2005). With the reduced forage production, maintaining ruminants year-round is difficult, resulting in lower manure availability for returning to cultivated land plots.

Ley pastures based on domesticated grasses and legumes are a possible solution for restoring soil fertility, considering the limited financial resources of the small farms (reviewed by Adjolohoun *et al.* 2008a). Yield and nutritive value of forage species adapted to the environmental conditions in the Sudanian region of west Africa have been studied (Adjolohoun *et al.* 2008b; 2008c), but information on their effects on soil fertility is lacking. This study aimed to evaluate the changes in chemical composition of the arable layer following a 3-year period under a number of unfertilised legume or grass leys.

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Materials and methods

Location and pre-experiment soil use

The experiment was carried out near Parakou, 300 m above sea level, in the savannah zone of Benin (west Africa) called the Borgou region (8°45'–12°30'N, 2°–3°15'E). Average annual rainfall is 1200 mm with unimodal distribution, and annual temperatures range between 26 and 28°C. Soil texture ranges from sand to sandy loam. Two adjacent sites (control and experimental) of 50 m × 50 m were chosen. They had been manually cleared in 1997, weed residues were burnt and the two sites were planted with yam in the first year, followed by maize and sorghum in the second year and cassava in Year 3 (1999).

Soil sampling procedures, forage species and sowing procedure

Following harvesting of the cassava at the beginning of 2000, 4 composite topsoil samples (0–10 cm) were collected from each site. Each composite sample consisted of 20 subsamples collected randomly from half of the diagonal at each site using an auger (5 cm diameter) and pooled using the "Four quadrants method" described by Rowell (1994). The control site was then fallowed with natural species and the experimental site was cultivated according to local practices prior to sowing with the experimental grass and legume species. The experimental site was divided into 40 plots (5 m x 4 m) with 1 m borders. There were 10 species treatments with 4 replications, arranged as a complete randomised block design.

The ley pastures were 4 grasses (*Panicum maximum* cv. C1, local *Andropogon gayanus* with broad leaves (BL), local *A. gayanus* with narrow leaves (NL) and local *Pennisetum purpureum*) and 6 legumes (*Aeschynomene histrix*, *Stylosanthes fruticosa*, *Centrosema pubescens*, *Mucuna pruriens* var. *utilis*, *Cajanus cajan* and *Leucaena leucocephala*), which are well adapted to the environmental conditions of the Borgou region (Adjolohoun et al. 2008a).

P. maximum and the *A. gayanus* cultivars were established at 50 cm intervals using rooted tillers (4–5 tillers/hole). *P. purpureum* was planted using stem cuttings (25–30 cm in length) at 1 m inter-vals. Legumes were planted from seed. *C. cajan* and *L. leucocephala* were planted at 100 cm spacings, while *A. histrix* and *S. fruticosa* were sown at 8 kg/ha in rows, 50 cm apart. Trailing species (*C. pubescens* and *M. pruriens*) were sown using 50 cm inter- and intra-row spacings and were thinned to 1 plant per hole 2 weeks after emergence. The plots were manually weeded each year during the rainy seasons (2000–2002).

At the end of the experiment, soil-samples (0–10 cm) were again collected with just one composite sample per plot.

Plant yields, forage analyses and nutrient removal

Two cuts were taken in Year 1 and 3 or 4 cuts in the second and third years, according to the development stage of the species. Cutting heights were 5–10 cm for prostrate species (*M. pruriens* and *C. pubescens*), 10–15 cm for erect herbaceous species (*A. histrix* and *S. fruticosa*), *P. maximum* and *A. gayanus*, and 30 cm for browse species (*C. cajan* and *L. leucocephala*) and *P. purpureum*. Dry matter (DM) yields were previously reported by Adjolohoun et al. (2008b; 2008c). Dried samples were milled to pass a 1 mm sieve using a Cyclotec 1093 Sample Mill (FOSS Electric A/S, Hilleroed, Denmark). For each species and each year, samples from the different harvests and different plots were pooled based on yields to provide a composite forage sample for analysis for mineral concentrations. K concentration was measured by atomic absorption spectrophotometry, total P by the colorimetric method using molybdovanadate reagent (Stewart et al. 1974) and N by the Kjeldahl method (method 981.10, AOAC 1990). The annual removal of each element was calculated by multiplying the DM yield of forage by the mineral concentration.

Grass root biomass measurement

At the end of the experiment, root sampling of the grasses was carried out using a trench profile method (Schuster 1964). Two sampling quadrats of 50 cm × 50 cm were randomly located within each of the 16 grass plots. In each quadrat, a 90 cm deep trench was excavated progressively in 9 successive layers of 10 cm. During excavation, the visible roots were gently separated using a

knife. Thereafter, the remaining small roots were carefully separated from the soil using a fine water spray and a 0.5 mm sieve. Root biomass (dry weight of the roots pooled for each plot) was determined after oven drying at 60°C for 2 days. The following ratios were calculated:

1. root nutrient uptake efficiency (%) (Rao *et al.* 1997) = [nutrient uptake in harvested forage (N, P, K in kg/ha) / root biomass (kg/ha DM)] x 100;
2. nutrient utilisation efficiency (Fageria 1992) = forage yield (kg/ha DM)/nutrient uptake (N, P, K in kg/ha).

Soil analyses

Soil samples collected at the beginning and the end of the experimental period were air-dried at room temperature and screened through a 2 mm mesh. The stone content was calculated as a percentage of the total mass of samples (Rowell 1994). The fine soil fraction (<2 mm) was analysed for moisture content by drying at 105°C for 24 hours. The $pH_{(water)}$ and $pH_{(KCl)}$ (pH KCl 0.1 N) were measured potentiometrically (pH-meter PHM82) using the method described by Laroche and Oger (1999) in a 2:5 soil:water suspension after equilibration for 4 hours. A subsample of the fine earth fraction was ground using a porcelain mortar to pass a 0.5 mm mesh sieve for C and N analyses. Organic carbon was analysed by dichromate oxidation (Springer and Klee 1954) and total N by the Kjeldahl method (method 981.10, AOAC 1990). Exchangeable forms of Ca, Mg, Na and K were extracted after saturation of the sorption complex with a buffered (pH 4.65) solution of 0.5 M CH_3COONH_4-0.002 EDTA with a ratio of 1:5 (Cottenie *et al.* 1982). Exchangeable Ca and Mg were determined by atomic absorption spectrophotometry and K and Na by flame emission spectrophotometry. Available P was extracted with 0.03 M NH_4F + 0.1 M HCl and was determined colorimetrically (spectrophotometer, CE 373) using the Scheel method (Cottenie *et al.* 1982). Textural analysis was done using the hydrometer method on raw soil which was sampled before planting.

Statistical analyses

The soil characteristics of both sites (granulometry, pH, exchangeable cations, available P, organic C and total N) were compared at the beginning of the experiment. As no significant differences were observed between sites, the average values for control and experimental sites are presented in Tables 1 and 2. The effects of treatments (10 species + control) on the granulometry and soil chemical characteristics (pH, exchangeable cations, available P, organic C and total N) at the end of the experimental period were analysed using the MIXED procedure of the SAS 8.02 software (SAS Inc., Cary, NC, USA). The means were classified as Least Squares Means using the following linear model:

$$Y = \alpha + A_i + e_{(ij)}$$

where Y is the result of the measurement, α is the overall mean, A_i is the fixed effect of the plant species ($i = 1-11$) and $e_{(ij)}$ is the error term. Plant root biomass production was analysed using the same procedure ($i = 1-4$).

Results

Soil texture and chemical composition

Coarse gravels represented 59 – 64% of the soil (data not presented). The fine fraction of soils (<2 mm) of both sites contained approximately 7 – 9% clay, 6 – 13% silt and 78 – 87% sand. Soil pH was in the neutral range (Table 1), while organic C and total N concentrations (Table 1) and exchangeable cations and available P concentrations (Table 2) were very low.

At the end of the study, soil chemical composition was significantly (P<0.05) different on the control and experimental plots (Tables 1 and 2). Soil pH under legumes (*A. histrix, S. fruticosa, C. pubescens, M. pruriens, C. cajan* and *L. leucocephala*) (pH 6.2–6.3) was significantly lower than those under grasses (pH 6.6–6.7). Soil organic C and N concentrations on the experimental plots had declined during the study and were lower than on the control site, where C and N concentrations remained unchanged. The declines were lower with *P. maximum, A. gayanus* and the tree legumes than with *P. purpureum* and the herbaceous legumes, which had the lowest soil C and N concentrations (Table 1).

Table 1. Characteristics (pH and organic C and N concentrations) of topsoil (0-10 cm) prior to and following 3-year grass and legume leys (n = 4).

	pH(water)	pH(KCl)	% C	% N
Pre-experimental	6.7	6.2	0.47	0.05
Situation after 3 years				
Control site				
(Natural fallow without exploitation)	6.6 a[1]	6.3 a	0.47 a	0.05 a
Experimental site (cut-and-carry system)				
P. maximum C1	6.6 a	6.1 a	0.35 b	0.04 a
A. gayanus BL	6.7 a	6.3 a	0.37 b	0.04 a
A. gayanus NL	6.6 a	6.2 a	0.32 b	0.02 b
P. purpureum	6.6 a	6.1 a	0.27 c	0.02 b
A. histrix	6.3 b	5.8 b	0.22 c	0.02 b
S. fruticosa	6.3 b	5.8 b	0.23 c	0.02 b
C. pubescens	6.3 b	5.6 b	0.23 c	0.02 b
M. pruriens	6.3 b	5.7 b	0.21 c	0.02 b
C. cajan	6.3 b	5.8 b	0.37 b	0.04 a
L. leucocephala	6.2 b	5.7 b	0.33 b	0.04 a

[1] Within columns, values followed by different letters differ (P<0.05).

Table 3. Average annual mineral removal during 3-year grass and legume leys (n = 4).

Species	DM yield[1] (kg/ha/yr)	Annual removal (kg/ha)			Nutrient-utilisation efficiency [ratio of biomass produced (kg) to nutrient removed (kg)]		
		N	P	K	N	P	K
Panicum maximum cv. C1	7312	110	7	78	66	1069	94
Andropogon gayanus BL	6425	108	6	38	59	1121	169
Andropogon gayanus NL	5271	72	4	31	73	1366	170
Pennisetum purpureum	4202	57	7	98	74	566	43
Aeschynomene histrix	2969	91	4	33	33	825	90
Stylosanthes fruticosa	2849	117	3	30	24	1014	95
Centrosema pubescens	2172	63	4	27	34	560	80
Mucuna pruriens	1478	57	3	15	26	511	99
Cajanus cajan	4764	130	8	46	37	598	104
Leucaena leucocephala	4140	168	6	48	25	690	86
s.e.m	408	11	0.53	6	8.8	310	51

[1] Adjolohoun *et al.* (2008b ; 2008c).

For all species, exchangeable cations and available P declined during the study (P<0.05) (Table 2). The pattern was similar to that for soil C and N, with smaller declines under *P. maximum, A. gayanus* BL, *C. cajan* and *L. leucocephala* than under *P. purpureum* and the herbaceous legumes (Table 2).

Nutrient removal

Removal of N in forage of *P. maximum* and *A. gayanus* BL annually was similar (110 and 108 kg/ha N, respectively), but more than that in *A. gayanus* NL and *P. purpureum* (72 and 57 kg/ha N) (Table 3). Among the legumes, *L. leucocephala* (168 kg/ha), *C. cajan* (130 kg/ha) and *S. fruticosa* (117 kg/ha) removed more N than *C. pubescens* (63 kg/ha) and *M. pruriens* (57 kg/ha). N-utilisation efficiency appeared similar for the different grasses and exceeded those for the legumes (Table 3). Removal of both P and K by grasses and legumes was quite variable, with P-utilisation efficiency generally higher in grasses than in legumes (Table 3). Removal of K

Table 2. Available phosphorus and exchangeable cation concentrations in topsoil (0-10 cm) prior to and following 3-year grass and legume leys (n = 4).

Species	Ca	Mg	K	Na	Sum of exchangeable cations	P	Ca:Mg	K:Mg	Ca:K	Ca:(Mg+K+Na)	(Ca+Mg):K
		(Cmol/kg)				(ppm)					
Pre-experimental	3.3	0.9	0.3	0.2	4.6	2.0	3.9	0.34	2.56	1.33	14
After 3-year leys											
Control site	3.9 a[1]	1.1 a	0.4 a	0.2 a	5.6 a	3.1 a	3.7 d	0.32 a	11 d	2.47 b	14 d
(Natural fallow without exploitation)											
Experimental site (cut-and-carry system)											
P. maximum C1	3.0 b	0.7 b	0.1 c	0.1 b	3.9 b	0.9 c	4.6 b	0.23 b	20 b	3.37 a	33 b
A. gayanus BL	3.1 b	0.7 b	0.2 b	0.1 b	4.0 b	1.3 b	4.5 bc	0.28 b	16 c	3.14 a	20 c
A. gayanus NL	2.7 c	0.6 b	0.1 c	0.1 b	3.4 b	0.8 c	4.9 b	0.18 c	27 b	3.61 a	32 b
P. purpureum	1.4 d	0.3 c	0.0 d	0.1 b	1.8 d	0.1 e	5.6 a	0.16 c	35 a	3.78 a	41 a
A. histrix	1.3 d	0.3 c	0.1 c	0.1 b	1.8 d	0.5 d	4.2 c	0.25 b	17 c	2.83 b	21 c
S. fruticosa	1.4 d	0.4 c	0.1 c	0.1 b	1.9 d	0.6 d	4.0 c	0.29 b	14 c	2.71 b	18 c
C. pubescens	1.5 d	0.4 c	0.1 c	0.1 b	2.0 c	0.6 d	4.1 c	0.24 b	17 c	2.90 b	21 c
M. pruriens	1.5 d	0.4 c	0.1 c	0.1 b	2.0 c	0.5 d	3.7 d	0.25 b	15 c	2.58 b	19 c
C. cajan	2.9 bc	0.7 b	0.2 b	0.1 b	3.8 b	1.8 b	4.5 bc	0.23 b	20 b	3.28 a	24 c
L. leucocephala	2.8 bc	0.6 b	0.2 b	0.1 b	3.7 b	1.5 b	4.7 b	0.36 a	13 cd	3.04 a	16 d

[1]Within columns, values followed by different letters differ (P<0.05).

Table 4. Root production, distribution through soil layers and nutrient uptake efficiency of 4 grasses following 3-year leys (n = 4).

Species/Soil layer (cm)	Total root weight (kg/ha DM)										Root nutrient uptake efficiency (%)[1]		
	0-90	0-10	10-20	20-30	30-40	40-50	50-60	60-70	70-80	80-90	N	K	P
P. maximum cv. C1	2380 a[2]	1536 a	405 a	167 a	143 a	71 b	48 b	10 b	0 b	0 b	4.62	0.29	3.28
A. gayanus BL	2145 a	1180 b	386 a	150 ab	129 b	107 a	83 a	64 a	31 a	15 a	5.03	0.27	1.77
A. gayanus NL	1540 b	893 c	308 b	139 b	92 c	62 b	31 b	15 b	0 b	0 b	4.68	0.25	2.01
P. purpureum	1245 c	784 c	261 c	112 c	75 c	13 c	0 c	0 c	0 b	0 b	4.58	0.60	7.87

[1] Nutrient uptake (kg)/ root weight (kg).
[2] Within columns, values followed by different letters differ (P<0.05).

in *P. purpureum* (98 kg/ha/yr) was higher than for all other species and its efficiency of utilisation of this nutrient was the lowest among the 10 tested species (Table 3).

Root production of the grasses

Total production of root DM and its distribution throughout the soil profile varied among the 4 grasses tested (Table 4). *P. maximum* and *A. gayanus* BL produced more root growth (P<0.05) than the remaining species, especially in the top 40 cm of soil. Only *A. gayanus* BL produced roots below the 70 cm horizon, while *P. purpureum* produced none below 50 cm. Visual observations showed also that there were differences between the grasses in root thickness, with thickness ranked as follows: *P. maximum* cv. C1 > *A. gayanus* NL type > *A. gayanus* BL type > *P. purpureum* (data not presented).

Root nutrient uptake efficiencies for K and P were much higher for *P. purpureum* than for the remaining grasses.

Visual observations showed that root development of legumes, particularly of the herbaceous species, was very poor and no sampling was conducted.

Discussion

This study has produced valuable information on the chemical changes in top soil under a number of grass and legume leys, utilised in a cut-and-carry system over a period of 3 years. To our knowledge, there is no comparable information in the literature on the influence of these plant species on soil nutrient levels under a cut-and-carry management system in the absence of fertiliser input. Declining soil nutrient levels were recorded under all species, even for N under the 6 legume species tested. This was somewhat surprising given the expected potential for N-fixation by legumes. Visual observation suggested that nodule production by legumes was low (data not shown). At sowing, legume plants were deliberately not inoculated in order to favour species that could nodulate with native *Rhizobium* and survive under the conditions prevailing in the experimental area as suggested by Tarawali *et al.* (1995). At the end of the study, the area which had been naturally fallowed contained higher

soil nutrient levels than the area which had been sown to the introduced species and harvested for feeding to stock.

Coarse-textured soils are usually favourable for pasture production as they are well drained. These characteristics favour rapid mineralisation of organic matter, nutrient leaching and rapid soil nutrient depletion, where slash and burn land preparation is practised. Initial pH levels of the soil were close to neutral and within the optimal range for growth of the tested grasses and legumes (Cook *et al*. 2005). Soil N, P and K concentrations were in the ranges reported by other authors for west African savannah soils (Worou 2002; Kissou *et al*. 2002; Saïdou 2006) and were very low for adequate forage production levels. The annual DM yields of the grasses of 4.2–7.3 t/ha (Adjolohoun *et al*. 2008b; 2008c) reflected the poor nutrient status of the soils. Weak root development of the herbaceous legumes lead to much lower fixation of atmospheric nitrogen than expected with such species, questioning the use of such species for ley pastures without inoculum and adequate strategies to maintain nutrients within the production system (P and K).

The strong differences between the grass species in nutrient removal are of interest. Not only did *P. maximum* cv. C1 and *A. gayanus* BL type remove more C and N from the system in harvested forage than the remaining grasses, but also the soils under these grasses contained more C and N than under the other grasses at the end of the study. While the greater rooting depth of *A. gayanus* BL might have allowed it to source nutrients from deeper soil layers, the root distribution of *P. maximum* was similar to that of *A. gayanus* NL. Roots of *P. purpureum* were confined mainly to the top 40 cm of soil. However, this species was very efficient at extracting P and K from the soil, indicating the need to provide adequate levels of these nutrients in any fertiliser programme.

The ability of all grass species to produce as much forage as they did in such infertile soils can probably be ascribed to their deep root development and exploitation of so much soil, especially for *P. maximum* and the *A. gayanus* ecotypes. The development of deep roots is also important for the persistence of forages in the dry season. The limited root depths recorded in this trial compared with previous observations (CIAT 1978; Buldgen and Dieng 1997; Groot *et al*. 1998) are a function of the shallowness (0.4–1 m) of ferru-

ginous arable soils characteristic of the savannah region of Benin.

It is of interest that root DM production of the grasses mirrored foliage DM production (*P. maximum* C1 = *A. gayanus* BL type > *A. gayanus* NL type > *P. purpureum*) (Tables 3 and 4). Indeed, differences in root biomass and root morphology frequently lead to differences in nutrient uptake, owing either to improved proximity to nutrients, as is the case with a large root system, or more efficient physiological processes, as in the case of higher rates of nutrient uptake per unit of root biomass or length (Rao *et al.* 1997; Wang *et al.* 2001, 2003).

While *P. purpureum* showed the lowest foliage DM production of the 4 grasses, surprisingly, it had the highest P and K root nutrient uptake efficiencies (Table 4). This suggests that it is not a suitable species for ley pasture in the Borgou region, as it could induce rapid depletion in soil fertility as highlighted in this study by the higher Ca:K and lower K:Mg ratios in the soil after 3 years of cultivation (Table 2) without producing acceptable DM yields.

It is a deficiency in our experimental design that we did not measure root development in the legumes. Nevertheless, shrub legumes such as *C. cajan* and *L. leucocephala* are known to have deeper root systems than herbaceous legumes. This ability to exploit deeper layers in the soil profile could account for their higher yields and higher mineral uptake. The reduction in soil pH under all legume species supports earlier reports (Haynes 1983; Conventry and Slattery 1991) that legume-based production systems cause an acidification of the soil. While this is not an issue in short-term leys, it is a cause for concern in permanent legume-based pastures.

It can be concluded that, without a strategy to prevent nutrient rundown, ley pastures of both legumes and grasses are not sustainable in this region. For grasses, a minimum input of NPK fertiliser, consisting of 50 kg N, 3 – 5 kg P and 20 – 50 kg K, must be recommended in such short-term ley pastures. However, the need for fertiliser in such a cut-and-carry system can possibly be managed by returning the manure from housed animals to the fields. Further studies to test this hypothesis seem warranted. Inoculation of legumes with appropriate rhizobia should be tested before they are discarded as possible ley species.

Acknowledgements

References

ADJOLOHOUN, S., BINDELLE, J., ADANDÉDJAN, C. and BULDGEN, A. (2008a) Some suitable grasses and legumes for ley pastures in Sudanian Africa: the case of the Borgou region in Benin. *Biotechnology, Agronomy, Society and Environment*, **12**, 405–419.

ADJOLOHOUN, S., BULDGEN, A., ADANDÉDJAN, C. and DARDENNE, P. (2008b) Yield and nutritive value of three grass species tested as ley pasture in the Borgou region of Benin. *Tropical Grasslands*, **42**, 237–244.

ADJOLOHOUN, S., BULDGEN, A., ADANDÉDJAN, C. and DECRUYENAERE, V. (2008c) Yield and nutritive value of herbaceous and browse forage legumes in the Borgou region of Benin. *Tropical Grasslands,* **42**, 104–111.

AOAC (1990) *Official Methods of Analysis*. 15th Edn. (Association of Official Analytical Chemists: Arlington, VA).

BULDGEN, A. and DIENG, A. (eds) (1997) Andropogon gayanus var. bisquamulatus. *Une culture fourragère pour les régions tropicales.* (Les Presses Agronomiques de Gembloux: Gembloux).

CIAT (1978) *Annual report of the Centre for International Tropical Agriculture.* (International Centre for Tropical Agriculture: Cali, Colombia).

CONVENTRY, D.R. and SLATTERY, W.J. (1991) Acidification of soil associated with lupins grown in a crop rotation in south-eastern Victoria. *Australian Journal of Agricultural Research,* **42**, 391–397.

COTTENIE, A., VERLOO, M., KIEKENS, L., VELGH, G. and CAMERLYNCH, R. (1982) *Chemical analysis of plants and soils*. (Laboratory of Analytical and Agrochemistry, Ghent State University: Ghent).

COOK, B.G., PENGELLY, B.C., BROWN, S.D., DONNELLY, J.L. *et al.* (2005) *The Production of Tropical Forages: An alternative selection tool.* http://www.tropicalforages.info (Accessed Oct. 2009).

FAGERIA, N.K. (1992) *Maximizing Crop Yields.* (Marcel Dekker Inc.: NewYork).

GROOT, J.J.R., TRAORÉ, M. and KONÉ, D. (1998) Description du système racinaire de trois espèces fourragères en zone soudano-sahélienne : *Andropogon gayanus, Vigna unguiculata* et *Stylosanthes hamata. Biotechnology, Agronomy, Society and Environment,* **2**, 106–119.

HAYNES, R.J. (1983) Soil acidification induced by leguminous crops. *Grass and Forage Science,* **38**, 1–11.

KISSOU, R., THIOMBIANO, L., NEBIE, A.K., SEMDE, A. and YAGO, K.J. (2002) La Base mondiale de données sur les sols: avantages et faiblesses pour la connaissance et l'utilisation des milieux édaphiques au Burkina Faso. *Quatorzième Réunion du sous-comité Ouest et Centre Africain de corrélation des sols pour la mise en valeur des terres, Abomey, Bénin, 2000.* (FAO: Rome).

KOUTIKA, L.S., SANGINGA, N., VANLAUWE, B. and WEISE, S. (2002) Chemical properties of soil organic matter assessment under fallow systems in the forest margins benchmark. *Soil Biology and Biochemistry,* **34,** 757–765.

LAROCHE, J. and OGER, R. (1999) *Base de données sol - première synthèse.* (Requasud: Gembloux).

NIKIEMA, A. (2005) *Agroforestry Parkland species diversity: Uses and Management in Semi Arid West Africa (Burkina Faso).* Ph.D. Thesis. Wageningen University.

RAO, I.M., BORRERO, V., RICAURTE, J., GARCIA, R. and AYARZA, M.A. (1997) Adaptive attributes of tropical forage species to acid soils. III. Differences in phosphorus acquisition and utilisation as influenced by varying phosphorus supply and soil type. *Journal of Plant Nutrition,* **20,** 155–180.

RETHMAN, N. (2000) Grass, grass-legume or legume leys: a south African experience. *Tropical Grasslands,* **34,** 177–180.

ROWELL, D.L. (1994) *Soil Science: Methods and Applications.* (Longman: Essex).

SAÏDOU, A. (2006) *Converting strategies by Farmers and Scientists to improve Soil Fertility and Enhance Crop-Production in Benin.* Ph.D. Thesis. Wageningen University.

SCHUSTER, J.L. (1964) Root development of native plants under three grazing intensities. *Ecology,* **45,** 63–70.

SOMÉ, N.A., TRAORÉ, K., TRAORÉ, O. and TASSEMBEDO, M. (2007) Potentiel des jachères artificielles à *Andropogon* spp. dans l'amélioration des propriétés chimiques et biologiques des sols en zone soudanienne (Burkina Faso). *Biotechnology, Agronomy, Society and Environment,* **11,** 245–252.

SOUMARÉ, M., DEMEYER, A., TACK, F.M.G. and VERLOO, M.G. (2002) Nutrient availability in the surface horizons of four tropical agricultural soils in Mali. *Tropicultura,* **20,** 58–63.

SPRINGER, U. and KLEE, J. (1954) Prüfung der Leistungsfähigkeit von einigen wichtigeren Verfahren zur Bestimmung des Kohlemstoffs mittels Chromschwefelsäure sowie Vorschlag einer neuen Schnellmethode. *Zeitschrift für Pflanzenernährung, Düngung, Bodenkunde,* **64**, 1.

STEWART, E.A., GRIMSHAW, H.M., PARKINSON, J.A. and QUARMBY, C. (1974) *Chemical analysis of ecological materials.* (Blackwell Scientific Publications: Oxford).

TARAWALI, S.A., TARAWALI, G., LARBI, A. and HANSON, J. (1995) *Methods for the Evaluation of Legumes, Grasses and Fodder Trees for Use as Livestock Feed. ILRI Manual 1.* (International Livestock Research Institute: Nairobi).

WANG, Z.Y, GÖTTLEIN, A. and BARTONEK, G. (2001) Effects of growing roots of Norway spruce (*Picea abies* [L.] karst.) and European beech (*Fagus sylvatica* l.) on rhizosphere nutrient chemistry in a forest soil. *Journal of Plant Nutrition and Soil Science,* **164,** 35–41.

WANG, Z.Y., GÖTTLEIN, A. and RODENKIRCHEN, H. (2003) Soil exploration, nutrient partitioning, and nutrient efficiency of beech and spruce seedlings in a rhizotrone experiment. *Journal of Plant Nutrition and Soil Science,* **166,** 390–391.

WOROU, S.K. (2002) Sols dominants au Togo – corrélation avec la base de référence mondiale. *Quatorzième Réunion du sous-comité Ouest et Centre Africain de corrélation des sols pour la mise en valeur des terres, Abomey, 2000.* (FAO: Rome).