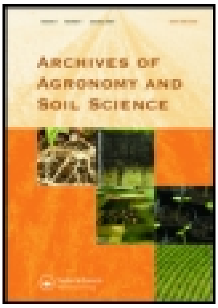

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Influence of *Panicum maximum* ecotypes on plant root growth and soil chemical characteristics after 3-year study in Soudanian region of West Africa

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A study was carried out to compare the influence of four Guinea grass ecotypes (*Panicum maximum*) differing in their morphological, physiological, and agronomical traits on soil fertility in Soudanian region of West Africa. Plants were sown in a randomized complete block design with four replicates and cultivated during three successive years under a cut-and-carry regime without any fertiliser use. A natural fallow served as the control. Soil samples were collected before and after cultivation, and analyzed for pH, organic carbon, nitrogen, available P, and exchangeable cation contents. Aerial plant production was quantified and analyzed for N, P, and K content to estimate the uptake of these nutrients. Root biomass, depth, and distribution were also measured. Data were analyzed through ANOVA. After 3 years of cultivation, soil pH under plants did not vary but C and N concentrations declined from the initial levels. Owing to their deep rooting systems, two ecotypes can recycle nutrients apparently from deeper soil layers. While these ecotypes 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 seem warranted.

Keywords: Guinea grass; soil fertility; roots

Introduction

In West Africa regions, the land is continually under increasing pressure as a growing number of farmers attempt to improve their livelihood using extensive techniques, based solely on what the soil can naturally offer. Nowadays, low soil fertility constitutes a real constraint to crop yields (Soumaré et al. 2002; Saïdou 2006; Somé et al. 2007; Shoko et al. 2012) as fallow periods used to regenerate soils are increasingly shortened and eventually unable to restore fertility in traditional systems (Rethman 2000; Koutika et al. 2002; Nikiema 2005). Farms are also struggling to maintain ruminants year round due to reductions in forage production, thus also decreasing the availability of manure for application to cultivated land plots. Among the techniques used to improve or restore soil fertility, ley pastures based on cultivated forages constitute a possible solution, considering the weak financial resources of the small farms (reviewed by Adjolohoun et al. 2008). Ley pasture is generally an artificial or improved natural fallow and provides

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*Corresponding author. Email: s.adjolohoun@yahoo.fr more grass or legume forage plants for ruminants than natural fallow, which contains more unpalatable species.

Guinea grass is native to Africa with an extension zone from 20° N to 20° S and from sea level to 2500 m and above. It belongs to a very diverse genus (*Panicum*). The diversity in the genus has led to a confusing taxonomy and the delimitation of the genus is not entirely clear. Current names in use to describe *Panicum maximum* are *Urochloa maxima* (Jacq.) R. Webster (ITIS 2012) and *Megathyrsus maximus* (Jacq.) B. K. Simon and S. W. L. Jacobs (Simon & Jacobs 2003). As the confusion surrounding the placement of *P. maximum* in the classification has not been settled, this article uses *Panicum maximum* as the name of the plant, following the definition used in the world grass species database of the Royal Botanical Garden at Kew (Clayton et al. 2006).

The study has been conducted on *P. maximum* ecotypes diversity and their forage production and nutritive value in the environmental conditions of West Africa (Adjolohoun et al. 2012); however, there is no information about soil fertility evolution, especially for short periods of ley. Evaluating and understanding soil fertility trends under ley pasture is essential to choosing the best suited forage ecotypes for the Soudanian region of West Africa, considering both soil nutrient uptake and soil fertility reclamation. This study aimed to evaluate the trends in soil chemical characteristics and the nutrient uptake of different forage ecotypes planted in artificial ley-pastures, after a short period (3 years) of exploitation without any addition of fertilisers.

Materials and methods

Study site and design

The experiment was carried out near Samiondji Farm, located in the *Agonli* region (7° 60′ N, 2° 54′ E), 75 m above sea level, in the savannah zone of West Africa. The experimental site is characterized by an average rainfall of 1100 mm per year with a unimodal distribution. Mean annual temperatures range between 26°C and 28°C and the soil texture was sandy (89%). At the beginning of this experiment in 2009, two adjacent sites of $50 \times 50\ \mathrm{m}^2$ were chosen. The first site (control site) was previously cultivated and then, 3 years of fallowing was observed. The second experimental site was also cultivated in the same conditions as the first experiment, and used to test the forage ecotypes. The control and experimental sites were manually cleared in 2006, weed residues were burnt and the two sites were planted with yam the first year, followed by maize and sorghum the second year, and cassava in third year (2008). During the 3-year experiment, neither fertilizer nor irrigation was used.

Soil sampling procedures, forage ecotypes, and plant sowing

After harvesting cassava at the beginning of 2009, four half-diagonals of each site (control and experimental) were delimited. On each half-diagonal, 20 sample soils (0–15 cm) were collected randomly using an auger (5 cm diameter). Twenty samples collected in each half-diagonal were pooled to constitute a composite sample, and a subsample was taken using the ‘Four quadrants method’ described by Rowell (1994). This allowed taking four composite samples (experiment units for statistical analyses) per site at the beginning of the experiment. Soil samples were analyzed and two site soil mineral contents (before plant establishment) were compared. No significant difference was observed between them (two sites) and then their means are considered (values before experiment in Table 3).

Table 1. *P maximum* ecotypes used in this trial.

Ecotype	Plant height	Leaf length (cm)	Leaf width	Dry season resistance	Leaf/ steam (ratio)	Days to first flower (weeks)	Inflorescence length (cm)	Forage ash content (%)
Ecotype LHLL[a]	166	55	2.6	High	1.02	12.6	39	5.77
Ecotype MHML[b]	258	76	3.4	Medium	0.99	10.7	60	10.01
Ecotype MHHL[c]	233	107	3.7	Very high	0.75	9.5	41	7.43
Ecotype HHLL[d]	430	47	2.5	Low	1.05	9.0	114	15.03

Note: [a]Ecotype LHLL is characterized by low height and low leaf length and width; [b]ecotype MHML is characterized by medium height and medium leaf length and width; [c]ecotype MHHL is characterized by medium height and high leaf length and width; [d]ecotype HHLL is characterized by high height and low length and width. Source: Adjolohoun et al. (in press).

After the first soil sampling, the control site was fallowed (natural species) and the experimental site was immediately cleared, ploughed, and harrowed according to local practices. The experimental site was divided into 16 plots (7 × 7 m^2) spaced 2 m-apart from each other.

Four grasses described in Table 1 were used for the experiment. They are perennial grasses and characterized by different morphological and physiological traits (Adjolohoun et al. 2012). They have showed their best forage dry matter (DM) production. Ecotype LHLL was characterized by low height, and small length, and width of leaves. Ecotype MHML had medium height and medium leaf length and width. Ecotype MHHL showed medium height and high leaf length and width, and ecotype HHLL was characterized by high height and low length and width (Table 1). All ecotypes were established 40 cm apart using rooted tillers (4–5 tillers per plantation hole) given density of 62,500 plants ha^{-1}. Each plant (ecotype) was considered as treatment with four replicates, giving a total of 4 × 4 = 16 plots arranged in a randomized complete block design. Plots were manually weeded each year during the three experimental rainy seasons (2009–2011). At the end of the experiment, 20 soil samples (0–15 cm) were taken on both diagonals of each plot. They were thereafter pooled to constitute one composite soil sample from which a subsample was taken as described above. This allowed taking one composite sample per plot, allowing four composite samples (experimental units) per ecotype after the 3-year experiment. For the control site (natural fallow), soil was also sampled after 3 years, as described, before plant establishment, giving four composite samples for statistical analyses (situation after 3 years for control site, Table 3).

Plant yield, and nutrient concentration and uptake

At the beginning of each year, a standardization cut was done at the suitable height of 15 cm to promote the growth of a uniform stand without recording the biomass production data. During each experimental year, three cuts were practiced according to the 5-6-5-week cutting regime. The first cut has been down 5 weeks after standardization cut, the second 6 weeks after the first cut, and the third 5 weeks after the second. This cutting regime was chosen as it had showed its best influence on both dry matter production and nutritive value of harvested forages in the region. Above-ground edible forage (leaves and sheath) was considered for nutrient content determination. Dry matter (DM) yields were previously reported by Adjolohoun et al. (in press). DM samples were milled to pass a 1 mm sieve using a Cyclotec 1093 Sample Mill (FOSS Electric A/S, Hilleroed, Denmark) for further chemical analysis. For each ecotype and each cultivation year, samples from the different harvests and different plots were pooled together based on their weight in order to constitute a composite forage sample that was used for mineral content determination. Samples were digested with concentrated HNO_3–H_2O_2 at 120°C during 3 hours in a Teflon digester. Digested samples were thereafter diluted with distilled water. Total K contents were measured by atomic absorption spectrophotometry using an AAS-800 spectrophotometer (Perkin Elmer, Wellesley, MA, USA). Total P content was determined by the colorimetric method using molybdovanadate reagent (Stewart et al. 1974) and total N content by the Kjeldahl (block digestion) method (AOAC 981.10) (AOAC 1990). For each mineral, the annual nutrient uptake of forages (above-ground biomass) was calculated as

$$\text{Nutrient uptake}\,(\text{kg ha}^{-1}) = \text{DM yields} \times \text{mineral content}. \tag{1}$$

Root biomass

At the end of ecotype cultivation, root sampling was carried out using a trench profile method (Schuster 1964). This method was selected because, when compared to dicotyledons, their fasciculated roots may indicate different soil layers and eventually explain some results. Two sampling quadrats of 50 × 50 cm^2 each were randomly located within each of the 16 plots. In each quadrant, a trench of 90 cm was excavated progressively in nine successive layers of 10 cm each. During excavation, the visible roots were gently isolated using a knife. Thereafter, the remaining roots (of small size) were carefully separated from the soil using a fine water spray and a 0.5 mm sieve. Root dry biomass was determined after oven drying at 60°C for a two-day period. Mean of two quadrats of each plot was considered for statistical analysis. Two ratios were calculated as follows:

$$\begin{aligned}&\text{Root nutrient} - \text{uptake efficiency}\,(\%)(\text{Rao et al. 1997})\\&= \text{Nutrient uptake of aboveground biomass}\,(\text{N, P, and K in kg ha}^{-1})/\\&\quad\text{Root biomass}(\text{kg DM ha}^{-1}) \times 100;\end{aligned} \tag{2}$$

$$\begin{aligned}&\text{Nutrient utilization efficiency (Fageria 1992)}\\&= \text{Dry matter yield of aboveground biomass}\,(\text{kg DM ha}^{-1})/\\&\quad\text{nutrient uptake}\,(\text{N, P, K in kg ha}^{-1}).\end{aligned} \tag{3}$$

Soil analysis

Soil samples collected at the beginning and at the end of the experimental period were air dried at room temperature and screened through a 2-mm mesh. The stone content was assessed as a percentage by mass of samples (Rowell 1994). The fine soil fraction (<2 mm) was analyzed for its moisture content by drying at 105°C for 24 hours. The pH_{water} and pH_{KCl} (pH_{KCl} 0.1 N) were measured potentiometrically (using the pH meter PHM82, Copenhagen, Denmark) using the method described by Laroche et al. (1999) in a ratio of 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 prior to C and N analysis. Organic carbon was analyzed using a modified Springer–Klee method consisting of oxidation with 0.33N $K_2Cr_7O_7$ at 160°C in acidic condition (Alef and Nannipieri 1995). Total N was determined by the Kjeldahl method (AOAC 981.10). Exchangeable 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. Exchangeable K and Na contained in the solution were determined with flame emission spectrophotometry. Available P was extracted with 0.03 M NH_4F + 0.1 M HCl (Bray extract) and was determined colorimetrically (spectrophotometer, CE 373, Cambridge, UK) using the Scheel method (Cottenie et al. 1982). Textural analysis was done using the hydrometer method on raw soil that was sampled before plant installation by rooted tillers.

Statistical analysis

Soil characteristics of control and experimental sites (texture, pH, exchangeable cations, available P, organic C, and total N) were compared at the beginning of the experiment. As no significant difference was observed for the investigated soil characteristics, the average value of both plot sites is presented in Tables 2 and 3. The influence of treatment (four ecotypes + control) on texture and soil chemical characteristics (pH, exchangeable cations, available P, organic C, and total N) at the end of the experimental period was analyzed using the MIXED procedure of the SAS 8.02 software (SAS Inc, Cary, NC, USA). The means were classified with least-squares means using the following linear model:

$$Y = \alpha + A_i + e_{(ij)}. \tag{4}$$

where Y is the result of the measurement, α is the overall mean, A_i is the fixed effect of the treatment (i = 1, 2, 3, 4, 5). and $e_{(ik)}$ is the error term. Plant root biomass productions were analyzed using the same procedure but for i = 1, 2, 3, 4. p-Value ≤ 0.05 was considered significant.

Table 2. Characteristics (pH and organic C and N concentrations) of topsoil 0–15 cm prior and following 3-year *Panicum maximum* ecotype leys (n = 4).

	pH_{water}	pH_{KCl}	% C	% N
Before experiment	6.5	6.0	0.52	0.08
Situation after 3 years				
Control site[a]	6.6a[b]	6.2a	0.52a	0.08a
Experimental site[c]				
Ecotype LHLL	6.5a	6.0a	0.42b	0.08a
Ecotype MHML	6.6a	6.1a	0.39b	0.05b
Ecotype MHHL	6.5a	6.0a	0.28c	0.03c
Ecotype HHLL	6.4a	5.8a	0.23c	0.01d
SEM	0.03	0.05	0.03	0.01
p-Values	0.320	0.120	0.007	0.002

Note: [a]Natural fallow without exploitation; [b]Within columns, means followed by different letters are significantly different (for p-values indicated); [c]Cut-and-carry system.

Table 3. Available *P* and exchangeable cation concentrations and ratios in topsoil (0–15 cm) prior and following 3-year ecotype leys ($n = 4$).

Ecotype	Ca ($\mathrm{cmol_c\ kg^{-1}}$)	Mg ($\mathrm{cmol\ kg^{-1}}$)	K ($\mathrm{cmol\ kg^{-1}}$)	Na ($\mathrm{cmol\ kg^{-1}}$)	Sum of exchangeable cations ($\mathrm{cmol\ kg^{-1}}$)	P ($\mathrm{mg\ kg^{-1}}$)	Ca/ Mg	K/ Mg	Ca/K	Ca/(Mg + K + Na)	(Ca + Mg)/K
Before	4.20[a]	1.11	0.40	0.31	5.80	4.01	3.80	0.36	11.00	2.33	13.01
Situation after 3-year											
Control site	4.68a	1.28a	0.48a	0.20a	6.23a	5.18a	3.60a	0.38a	8.75d	2.35b	12.00d
Experimental site[b]											
Ecotype LHLL	4.10b	0.90b	0.11b	0.13b	5.08b	3.93b	4.58b	0.11c	40.75b	3.73a	50.00b
Ecotype MHML	3.20c	0.75b	0.15b	0.11b	4.88b	3.00b	4.00b	0.25b	16.00c	2.91b	20.25c
Ecotype MHHL	1.43d	0.63bc	0.10b	0.13b	3.48c	2.50c	2.30c	0.17c	14.25c	1.75c	20.23c
Ecotype	1.53d	0.43c	0.00c	0.12b	1.85d	1.55d	3.80b	0.05d	75.25a	2.88b	95.25a
SEM	0.32	0.08	0.04	0.01	0.4	0.3	0.2	0.3	6.00	0.18	7
p-Values	0.001	0.008	0.003	0.04	0.000	0.001	0.033	0.017	0.000	0.007	0.000

Note: [a]Within columns, means followed by different letters are significantly different (for *p*-values indicated); [b]Cut-and-carry system.

Results

Soil texture and chemical parameter

Soil textures of both control and experimental sites were loam sandy with 78–87% of sand and 7–9% of clay with an important proportion of coarse gravels (59–64%). Soil organic carbon and nitrogen were low while pH_{water} was in the neutral range (Table 2).

After 3 years of cultivation, there was a significant difference ($p \leq 0.05$) between the control and tested plants in terms of soil chemical composition (Tables 2 and 3). The difference between pH_{KCl} and pH_{water} ranged from –0.4 to –0.6. Soil organic C and N contents were lower on the experimental site after 3 years of cultivation compared to the control site for which C and N contents remained similar to the initial situation. This decrease was, however, lower with ecotype LHLL and ecotype MHML compared to ecotype MHHL and ecotype HHLL, which gave the lowest soil C and N contents (Table 2).

A decrease was also observed for exchangeable cations for all species and available P after 3 years of cultivation ($p \leq 0.05$) (Table 3). Among the plots, soil under ecotype LHLL and ecotype MHML had similar sum of exchangeable cation (5.1 and 4.9 cmol kg^{-1}, respectively); however, the available P under the first plant (3.9 mg kg^{-1}) was higher ($p \leq 0.05$) than that under the second (3.2 mg kg^{-1}) (Table 3), which was significantly higher than that of ecotype MHHL (2.5 mg kg^{-1}) and ecotype HHLL (1.6 mg kg^{-1}). It appeared through these data analysis that soil properties have been affected after 3 years of *Panicum maximum* cultivation.

Nutrient uptake of above-ground biomass

P. maximum ecotype LHLL annually absorbed higher amount of N (74 kg ha^{-1}) than ecotype MHML (67 kg ha^{-1}). Ecotype MHHL took up significantly more N (40 kg ha^{-1}) than ecotype HHLL (Table 4). N-utilization efficiency appeared to be similar for the different ecotypes (Table 3). For phosphorus, ecotype LHLL removed from the soil more nutrient than the others ecotypes, which absorbed similar amounts of phosphorus. Potassium uptake of ecotypes ranged in the following order: LHLL (64 kg ha^{-1}) > ecotype MHML (57 kg.ha^{-1}) > ecotype MHHL (35 kg ha^{-1}) > ecotype HHLL (25 kg ha^{-1}) (Table 4). However, P- and K-utilization efficiency followed similar trends: ecotype LHLL = ecotype MHML = ecotype MHHL > ecotype HHLL (Table 5).

Table 4. Average annual mineral removal during 3-year *P. maximum* ecotypes leys (n = 4).

		Nutrient uptake (kg ha^{-1})			Nutrient utilization efficiency (kg DM ha^{-1}/kg nutrient ha^{-1})		
Ecotype	Dry matter yield (kg ha^{-1})	N	P	K	N	P	K
Ecotype LHLL	7112	74	6	64	96	1149	111
Ecotype MHML	5220	67	3	57	77	1538	92
Ecotype MHHL	3343	40	2	35	84	1613	94
Ecotype HHLL	1176	11	2	25	110	552	46
SEM	262	8	0.35	3	10	116	9

Note: SEM, standard error of the mean.
Source: Adjolohoun et al. (in press).

Table 5. Root dry matter, distribution through soil layers, and soil nutrient uptake efficiency of four *P. maximum* ecotypes following 3-year leys (n = 4).

	Total root weight (kg ha^{-1} DM)[a]										Root nutrient uptake efficiency (%)		
Ecotype/soil layer (cm)	0–90	0–10	10–20	20–30	30–40	40–50	50–60	60–70	70–80	80–90	N	P	K
Ecotype LHLL	3743a	1872a	749a	322a	299a	200a	112a	75ab	50a	25a	4.44	0.36	3.84
Ecotype MHML	2866b	1605a	516b	257b	172b	115b	86b	86a	30b	0b	5.21	0.23	4.43
Ecotype MHHL	1598c	767b	288c	176c	154c	80c	70b	64b	0c	0b	4.71	0.24	4.12
Ecotype HHLL	1276c	868b	255c	102c	51d	0d	0c	0c	0c	0b	2.89	0.52	6.56
SEM	341	171	70	32	26	23	14	10	6	3	–	–	–
p-Values	0.016	0.032	0.006	0.055	0.002	0.003	0.001	0.001	0.000	0.000	–	–	–

Note: [a]Within columns, values followed by different letters differ (for p-values indicated).

Root dry matter

The trial showed a difference in root DM production between four tested *P. maximum* ecotypes. Differences in root DM production were also observed between ecotypes through soil layers (Table 5). In 0–10 cm surface layer, Ecotype LHLL had the highest dry matter (3743 kg ha^{-1}) followed by ecotype MHML (2866 kg ha^{-1}) ($p \leq 0.05$). Ecotypes MHHL and HHLL produced less root dry matter (767 and 868 kg ha^{-1}, respectively) in the first 10 cm than the other two ($p \leq 0.05$). There was a significant difference ($p \leq 0.05$) between the four ecotypes' root dry matter production in the 10–30 cm layer. Overall, ecotype LHLL root dry matter per ha was significantly higher than that of ecotype MHML. Ecotypes MHHL and HHLL produced similar root dry matter per ha. Table 5 also shows a significant difference between ecotypes for the depth of their roots. On the basis of root biomass distribution through soil layer, ecotypes ranged in the following order: ecotype LHLL > ecotype MHML > ecotype MHHL > ecotype HHLL. Root nutrient uptake efficiencies were similar for ecotypes LHLL, MHML, and MHHL (Table 5). Ecotype HHLL had far lower root nutrient uptake efficiencies for N, P, and K than others.

Discussion

This trial had evaluated the influence of four *P. maximum* ecotypes on soil characteristics after 3 years of forage cultivation. Before plant establishment, soil pH in water and chloride solution was 6.5 and 6.0, respectively. These pH values are within the optimal range for growth of *P. maximum* species (Cook et al. 2005). Soil N, P, and K contents recorded in this study are in the ranges reported by other authors for West African Savannah soils (Saïdou 2006) and are very low to support an adequate forage production level over years. Soil organic carbon content (0.52%) is also in the range (0.27–0.60%) reported in similar regions of West Africa by Somé et al. (2006, 2007).

The difference between soil acidity measured in KCl and in water ($pH_{KCl} - pH_{water}$) before and after experiment (from –0.4 to –0.6) is low compared to the maximum difference of –1.5 that could be observed (Rowell 1994). This indicates that the base saturation of the sorption complex is probably high, despite a probably low exchange cation capacity as highlighted by the low cations content combined to a neutral soil pH. It is also consistent with the very high sand fraction and the low organic matter contents of the soils (Baize 2000). These observations were similar to those obtained by Youssouf and Lawani (2002) who reported that most of savannah soils in the savannah region of West Africa are highly saturated (85–95%). The sum of exchangeable cations also follows the normal order (Ca > Mg > K > Na) for most agricultural soils (Table 2) (Kissou et al. 2002).

In this trial, as one would expect, after 3 years of cultivation and cut-and-carry exploitation of the forages without any fertilization, all ecotypes decreased the topsoil (0–15 cm) fertility compared to the initial status and the 3 years of natural fallow, which was not exploited and where organic C, N, and exchangeable cations decreased. However, strong differences were observed between the species. The ecotypes LHLL and MHML were less depleting compared to ecotypes MHHL and HHLL. Despite the exploitation, those two ecotypes (LHLL and MHML) maintained a C/N ratio similar to that of the natural fallow and the sum of the exchangeable cations approached 80% of the natural fallow. To our knowledge, there is no information available in the literature comparing the influence of the tested plants on soil properties in such cut-and-carry management system without fertiliser input to allow data comparison.

The strong differences between nutrient removals of ecotypes in this study are of interest. It appeared at the end of the study that it is not only that the ecotypes LHLL and MHML removed more C and N from the system in the harvested forage than the remaining ecotypes, but also the soils under these ecotypes contained more C and N than under the two others. While the greater rooting depth of ecotype LHLL might have allowed it to source nutrients from deeper soil layers, the root distribution of ecotype MHML was similar to that of ecotype LHLL. Roots of ecotype HHLL were confined to the top 40 cm of soil. This result is important as it highlights that the great difference among *P. maximum* accessions reported by several authors (Chaume 1985; Aliscioni et al. 2003; Adjolohoun et al. 2012) is not only between morphological traits but also in root distribution through the soil profile. Nevertheless, in spite of the shallowness of ecotype HHLL (0–40 cm), this ecotype 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 accessions 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 the ecotypes LHLL and MHML. The development of deep roots is also important for the persistence of grasses in the dry season. The limited rooted depths recorded in this trial compared with previous observations (International Center for Tropical Agriculture 1978; Buldgen and Dieng 1997; Groot et al. 1998) are a function of the shallowness (0.4–1 m) of the arable characteristics of ferruginous soils of the savannah region of Benin.

It is of interest that the root DM production of the ecotypes mirrored foliage DM production (ecotype LHLL > ecotype MHML > ecotype MHHL = ecotype HHLL) (Tables 4 and 5). Indeed, differences in root biomass and root morphology frequently lead to differences in nutrient uptake, owing either to closer proximity to nutrients, as is the case of large root system, or to 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; Wang et al. 2003).

While ecotype HHLL showed the lowest foliage DM production of the four grasses, surprisingly, it had the highest P and K root nutrient uptake efficiencies (Table 5). This suggests that it is not a suitable ecotype for ley pasture in the region, as it could induce a rapid depletion in soil fertility as highlighted in this study by the higher Ca/K and the lower K/Mg ratios in the soil after 3 years of cultivation (Table 4) without producing acceptable DM yields.

Conclusion

In summary, this study has demonstrated a variability between *P. maximum* ecotypes for soil chemical modification, nutrient extraction from the soil, and soil depletion. On the other hand, plant ecotypes have shown significant difference for root biomass production and its repartition from soil profile. After 3 years of ley pasture, soil under the ecotypes LHLL, MHML, and MHHL was less depleted than that of ecotype HHLL. Those three ecotypes (LHLL, MHML, and MHHL) explored a deeper soil profile and produced more root biomass than ecotype HHLL. Nevertheless, ecotype HHLL had more efficiency for major elements (N, K, and P) extraction from soil than three others. Under the conditions of this experiment, it can be concluded that ecotypes LHLL, MHML, and MHHL are the most interested for both nutrient extraction and soil depletion. They could be used for ley pasture in the West Africa region. However, due to soil variability among regions and possible ecotype–environment interactions, we suggest that the study should be continued in other environments.

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