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Research Article

A Case of *Cyperus* spp. and *Imperata cylindrica* Occurrences on Acrisol of the Dahomey Gap in South Benin as Affected by Soil Characteristics: A Strategy for Soil and Weed Management

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Because of the limiting efficacy of common weed control methods on *Cyperus* spp. and *Imperata cylindrica* their occurrences in tropical agroecologies and the effect of soil properties in suppressing these species were investigated in south Benin (Cotonou), a typical ecology of the Dahomey gap. Weeds and soil samples were collected twice early and later in the rainy season in 2009 at four topographic positions (summit, upper slope, middle slope, and foot slope). Sampling was done according to Braun-Blanquet abundance indices (3 and 5) and the absence (0) of *Cyperus* and *Imperata* in a quadrat, respectively. The relationship between their respective abundances and soil parameters (texture, C, N, P, K, Na, Ca, Mg, and Fe) was explored. Weed occurrence was less related to soil texture, and *Imperata* growth was more influenced by soil nutrients (K, Ca, and Fe) than *Cyperus* spp. Soil cation ratios of K : Mg and Ca : Mg were the main factors that could be changed by applying K and/or Mg fertilizers to reduce *Cyperus* and/or *Imperata* occurrence. Maintaining high Fe concentration in soil at hillside positions can also reduce *Imperata* abundance, especially in the Dahomey gap.

1. Introduction

Weeds are notorious yield reducers that are, in many situations, economically more important than insects, fungi, or other pest organisms [1, 2]. The yield loss due to weeds is almost always caused by an assemblage of different weed species, and these can differ substantially in competitive ability [3]. In rice growing agro-ecologies of West Africa, weed species assemblages include nutsedges and speargrass that are perennial and serious threats [4].

Imperata cylindrica (L.) Raeuschel (speargrass) is a common and persistent weed in upland ecology. It reproduces through seeds and rhizomes. This weed is particularly difficult to control, as it is tolerant to fires and shallow cultivation due to its extensive underground network of rhizomes. The weed tends to be abundant where fields are regularly cultivated and burnt, as it recovers rapidly from disturbance, and burning induces flowering. It exerts great competition on crops [5, 6].

In moist to hydromorphic upland areas, some of the most intractable weed problems in rice are due to the perennial sedges *Cyperus rotundus* L. (purple nutsedge) and *Cyperus esculentus* L. (yellow nutsedge). Their tubers and seeds can remain dormant to survive periodic flooding or dry seasons. These species are able to multiply rapidly through tubers which can be greatly accelerated by soil tillage [7]. Because of these characters, *I. cylindrica* and *Cyperus* spp. are typical weeds of intensively cultivated lands and very difficult to control [8].

Some relative successes were observed using chemical methods for the control of *Cyperus* spp. and *I. cylindrica* [9]. But, herbicide is expensive and not always available to

West African smallholder farmers. Moreover, there is a risk of environmental pollution. Therefore, additional knowledge and technology are needed for improving the control of *Cyperus* spp. and *Imperata cylindrica* in Africa, especially in the Dahomey gap (south Benin) where they are seriously threatening livelihoods [10].

Considering that reduced soil fertility often increases weed infestation [11] and the effects of soil parameters in weed occurrence in Nigeria [12], the concept of chemotropism [13] is hypothesized in order to identify soil nutrients (N, P, K, Ca, Mg, and Fe) that influence the occurrence of *Cyperus* spp. and /or *Imperata cylindrical* attention should be paid to topography and soil texture influencing soil organic matter that can change vegetation structure [14].

A nonsite replicated ecological study [15] was initiated during the rainy season of 2009 along a catena of Acrisol in south Benin (West Africa), which is a typical ecology of the Dahomey gap. The implication of soil texture and nutrients (C, N, P, K, Ca, Mg, and Fe) on the occurrence of *Cyperus* spp. and *I. cylindrica* in this upland agro-ecology was explored. The aim was to identify soil parameters that can be used to develop a management strategy for the control of these perennial weeds in continued rice growing agro-ecologies of the Dahomey gap.

2. Materials and Methods

2.1. Site Description. The study was conducted during the 2009 cropping period (June–September) at the Africa Rice Center (ex-WARDA) experimental station in Cotonou (6° 28 N; 2° 21 E, 15 m asl), Benin. The site is a derived savanna zone in the Dahomey gap of West Africa. The rainfall pattern was bimodal with 807 mm during the cropping season of 2009. The soil is locally named "terre de barre." It is a very deep Acrisol (>10 m), with sandy top soil (0–40 cm) and free of constraints (gravels, stones, or hardpan) to plant rooting in the profile. Soil pH_{water} was 5 and C : N, Ca : Mg and K : Mg ratios were about 12, 1.7 : 1 and 1 : 1, respectively. The studied area is continuously cultivated for upland rice production.

2.2. Weed Sampling. Two dominance-abundance indices were considered for *Cyperus* spp. and *Imperata cylindrica* as a proportion of weeds in 1 m^2 quadrats: 3 = covering between 1/4-1/2 of the soil surface and 5 = covering more than 3/4 of the soil surface [16]. Weeds were also sampled where *Cyperus* and *Imperata* were absent, and zero (0) was the corresponding index. Indices 0, 3, and 5 were considered as absent (A), medium density (M), and high density (H), respectively. Three sampling places (A, M, and H) were identified for each of *Cyperus* spp. and *I. cylindrica* in the summit, the upper slope, the middle slope, and the foot slope as described by Ruhe and Walker [17]. Sampling was replicated twice in the studied site: in July (1) and in September (2) at the beginning and the end of the rainy season, respectively. In a quadrat, all the weed species were sampled separately with bellow ground dry matter. Individual identification was done as described by Akobundu and Agyakwa [18] and they were coded according to Braun-Blanquet [16]. The roots were cut off, and weeds were oven dried at 70°C for 24 hours before weighting.

2.3. Soil Sampling and Analysis. Topsoil (0–20 cm depth) was sampled using augur (20 cm × 7 cm) in each quadrat at every time of weed sampling. After sampling weeds, a soil sample was taken from the centre of the quadrat. Twenty-four (24) soil samples (12 at each sampling time) were taken, and sun dried before laboratory analysis. Soil particle sizes were determined by the Robinson pipette method [19] as well as organic-C, total-N, P-available (BrayI), and total-P (Pt). Soil exchangeable K, Ca, Mg, and extractable Fe were also determined. Chemical analyses were performed as described by Page et al. [20].

2.4. Statistical Analysis. Descriptive statistics were used to calculate the frequency of weed species in a specific quadrat. By analysis of variance (ANOVA), mean values of soil particle size and nutrients were determined for each topographic section. Mean values of total weed biomass dry matter were also determined for each placement of quadrat. The mean values were separated by Student-Newman and Keul methods. The relationships between biomass dry matter and soil physical and chemical characteristics were evaluated by Pearson correlation. SAS 10 package was used for these analyses. Soil clay, sand, C, N, Pa, K, Ca, Mg, and Fe concentrations were used to discriminate *Imperata* abundance indices (3 and 5) and absence (0) by canonical function analysis using SPSS 16.

3. Results

3.1. Soil Characteristics. The topsoil (0–20 cm) was sandy, and the middle slope (MS) had a significantly greater proportion of sand than other positions (Table 1). This topographic position also had significant lower contents of clay (11%) and silts (4%). The soil had moderate carbon content throughout the toposequence except in the soil at foot slope (FS) position; where it was significantly higher, similar gradient was observed for total nitrogen-Nt content along the toposequence. Phosphorus (P-available and P-total) contents were moderate in the soils of upper slope (US) and MS while they were higher in the soils at summit (SUM) and FS positions. Soil concentrations of divalent cations (Ca and Mg) were significantly higher at the SUM position with a decreasing trend along the toposequence. Similar result was observed for soil Fe concentration. Meanwhile, monovalent cations (K and Na) concentrations contrasting with these results with an increasing trend from the SUM to the FS.

3.2. Weed Assemblages. Seventeen weed species were most frequently encountered in the quadrats. Other species were also observed in at very low frequencies, and their cumulative frequencies were depressed in the medium and high densities of *Cyperus* spp. and *I. cylindrical,* respectively (Figure 1). However, more diverse communities were observed where *Cyperus* spp. and *I. cylindrica* were recorded in the quadrats compared to places where they were absent. Nevertheless, *Richardia brasiliensis* (Ricbr) was encountered in all quadrats with moderate (9.09%) to high (21.74%) frequency and *Dactyloctenium aegyptium* (Dacae) at a low frequency (2.56%–8.82%), about 14% in 1 m^2 characterized the medium density of *Cyperus* spp. and *I. cylindrica* occurrence, respectively.

Table 1: Mean values of soil particle sizes and nutrient contents (C, Nt, Pa, Pt, Mg, K, Ca, Na, and Fe) along the toposequence in topsoil (0–20 cm).

	Sand (%)	Clay (%)	Silt (%)	C-org (%)	Nt (%)	Pa (ppm)	Pt (ppm)	Mg (cmol kg^{-1})	Ca (cmol kg^{-1})	K (cmol kg^{-1})	Na (cmol kg^{-1})	Fe (ppm)
SUM	82.0^{b}	12.5^{ab}	5.5^{b}	1.19^{b}	0.07^{b}	26.4^{a}	170.8^{b}	2.8^{a}	2.9^{a}	0.2^{c}	0.05^{c}	2800^{a}
US	81.0^{b}	14.0^{a}	5.0^{c}	1.19^{b}	0.06^{c}	12.8^{b}	126.0^{c}	2.5^{b}	2.6^{b}	0.1^{d}	0.10^{c}	1960^{b}
MS	85.0^{a}	11.0^{b}	4.0^{c}	1.09^{b}	0.05^{d}	8.0^{b}	117.0^{c}	2.0^{c}	2.1^{c}	0.3^{b}	0.21^{b}	1924^{b}
FS	74.0^{c}	14.0^{a}	11.5^{a}	1.71^{a}	0.08^{a}	25.2^{a}	241.0^{a}	2.0^{c}	1.9^{d}	0.4^{a}	0.55^{a}	1547^{b}
$Pr > F$	<0.0001	0.001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001

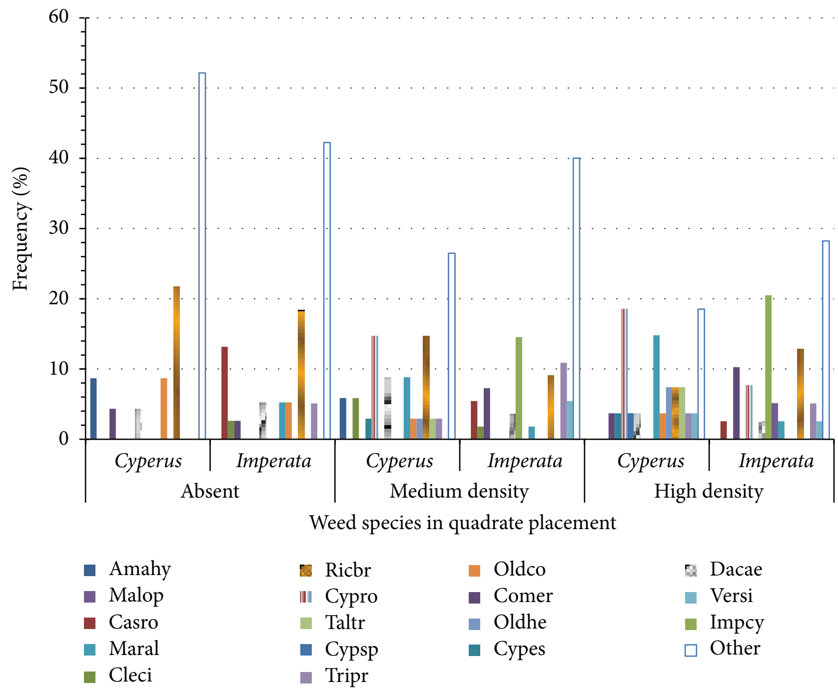

Figure 1: Weed specie average frequency in different placements of the quadrate.

Three species of *Cyperus* including *Cyperus esculentus*, *Cyperus sphacelatus,* and *Cyperus rotundus* were identified. But only *Cyperus rotundus* (Cypro) was encountered for the medium density of *Cyperus* spp. Whenever high densities of *Cyperus* and *Imperata* were observed, they accounted for 25.92% and 20.51%, respectively. *Commelina erecta* (10.26%) and *Richardia brasiliensis* (12.82%) were the most frequent weed species associated with the high density of *Imperata*.

Figure 2 shows the mean values of total weed biomass dry matter for each quadrat according to *Imperata* and *Cyperus* densities. Weed biomass was significantly higher in quadrats with high densities for *Imperata* and *Cyperus,* respectively. Wherever *Cyperus* and *Imperata* were absent, total weed biomass did not differ significantly with that observed for their medium densities.

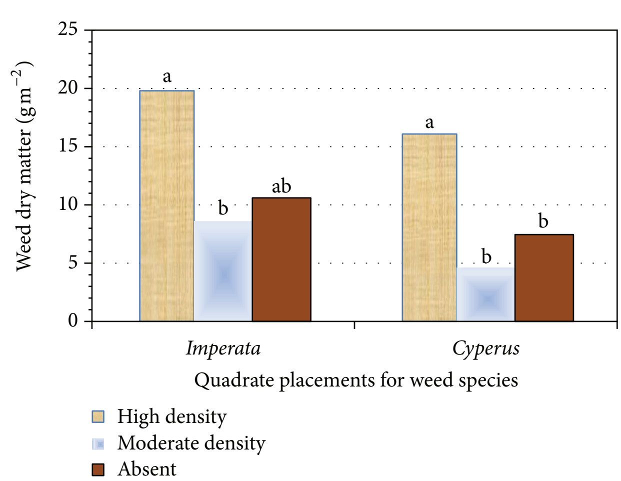

Figure 2: Weed biomass dry matter in quadrate placements for different densities of *Imperata* and *Cyperus* (a and b are indicating mean values that are different significantly).

3.3. Weed and Soil Relations. Table 2 shows the Pearson correlation values (R) between soil characteristics and the biomass of *Cyperus* and *Imperata,* respectively, when high

Table 2: Pearson correlation coefficient values between soil characteristics and the dry matter of *Cyperus* and *Imperata* in their respective high density quadrate placement.

	R	
	Cyperus biomass	*Imperata biomass*
Clay	−0.31	-0.66^{*}
Silt	−0.19	0.62^{*}
Sand	0.22	−0.02
C	−0.34	0.39
N	−0.39	−0.08
Pa	0.55	0.48
Pt	−0.13	−0.13
Mg	−0.11	−0.60
K	0.06	0.73^{**}
Ca	−0.36	-0.84^{**}
Na	−0.29	0.54
Fe	0.03	-0.88^{**}

*significant at 10%; **significant at 1%.

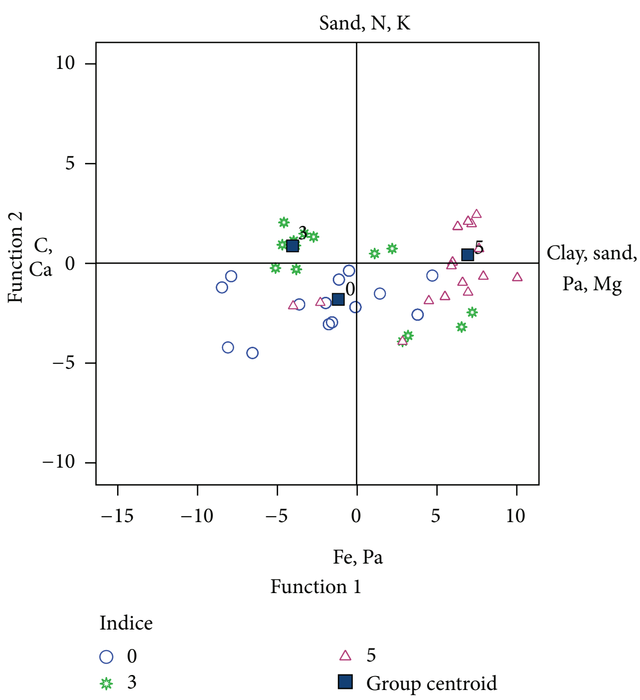

Figure 3: Canonical function discrimination of *Imperata* abundance according to soil parameters.

densities were observed. Carbon-C (−0.34), N (−0.39), Pa (0.55), and Ca (−0.36) had highest correlation values with *Cyperus* biomass, but these results were not significant. Meanwhile, highly significant ($P < 0.01$) correlations were observed between the biomass of *Imperata* and K (0.73), Ca (−0.84), and Fe (−0.88) concentrations in the soil. Moreover, clay (−0.66) and silt (0.62) had significant correlation with *Imperata* biomass at certain level of probability ($P = 0.1$).

Figure 3 shows that group centroids (mean of the discriminant score for a given category of dependant variable)

Table 3: Mean values of clay, silt, Fe, K, and Ca contents in soil at different topographic positions for different abundance of *Imperata*.

		Clay	Silt	Fe	K	Ca
		%		(ppm)	cmol kg^{-1}	
SUM	A	9^{c}	5^{b}	3277.87^{b}	0.02^{b}	3.32^{a}
	M	10^{b}	6^{a}	1506.75^{c}	0.01^{c}	2.84^{b}
	H	14^{a}	6^{a}	3509.50^{a}	0.04^{a}	3.28^{a}
$P > F$		<0.0001	0.006	<0.0001	<0.0001	<0.0001
US	A	14^{b}	5^{b}	2584.94^{a}	0.05^{b}	2.87^{a}
	M	12^{a}	4^{c}	654.08^{c}	0.03^{c}	2.90^{a}
	H	13^{b}	8^{a}	2330.99^{b}	0.08^{a}	2.88^{a}
$P > F$		<0.0001	<0.0001	<0.0001	<0.0001	0.272
MS	A	10^{a}	4^{b}	2366.19^{a}	0.18^{c}	2.00^{c}
	M	7^{c}	5^{a}	1018.08^{c}	0.30^{a}	2.19^{b}
	H	9^{b}	3^{c}	2046.45^{b}	0.23^{b}	2.44^{a}
$P > F$		<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
FS	A	10^{a}	9^{c}	591.65^{c}	0.36^{b}	2.87^{a}
	M	10^{a}	11^{a}	4498.86^{a}	0.41^{a}	2.02^{c}
	H	9^{b}	10^{b}	1269.39^{b}	0.21^{c}	2.25^{b}
$P > F$		<0.0001	<0.0001	<0.0001	<0.0001	<0.0001

SUM: Summit; US: upper slope; MS: middle slope; FS: foot slope; A: absent; M: moderate density; H: high density; ^{a,b,c}are indicating mean values that are significantly different.

of *Imperata* abundance indices are well separated, attesting the ability of soil parameters (clay, sand, Pa, C, N, K, Ca, Mg, and Fe) to discriminate *Imperata* density: absence was mainly characterized by lower Fe and Pa concentrations in soil, while increasing of soil sand, clay, Pa, and Mg was characterized by abundance (5). The medium (3) density of *Imperata* was observed for low soil C and Ca contents.

Table 3 shows variance of these relationships according to topographic positions. In fact, the highest soil clay (14%), Fe (3509.5 ppm), and K (0.04 cmol kg^{-1}) concentrations were associated with the abundance of *Imperata* at the summit. However, the absence of *Imperata* at the US and MS positions was more related to high soil Fe concentration. Highest (US) and lowest (MS) K concentration in soil characterized the highest density and the absence of *Imperata,* respectively, according to topographic positions. Soil calcium concentrations were not significantly different for the absence and the high density of *Imperata* at the SUM and the US. In contrast, the highest (2.44 cmol kg^{-1}) and lowest (2.00 cmol kg^{-1}) soil Ca concentrations were related to high density of *Imperata* at the FS and MS positions, respectively.

4. Discussion

4.1. Extension and Limit of Our Finding. *Cyperus esculentus*, *Cyperus sphacelatus,* and *Cyperus rotundus* were encountered in the studied area. The last species was the most frequent along the toposequence compared to the others. However, the occurrence of *Cyperus sphacelatus* contrasts with observations by Johnson [5] who mentioned the occurrence of *Cyperus difformis* in rice agro-ecosystems rather than

C. sphacelatus. *Dactyloctenium aegyptium* (Dacae), *Richardia brasiliensis* (Ricbr), and *Commelina erecta* (Comer) were the most frequent weed species associated with *Cyperus* and *Imperata* according to our study which differs from previous knowledge of weed community in upland ecology of West Africa [8]. Furthermore, *Andropogon*, *Cymbopogon*, *Hyparrhenia*, *Pennisetum*, and *Setaria* were frequently encountered in the southern guinea savanna including *Brachiaria* spp. instead of *Setaria* identified in the northern guinea savanna of West Africa [21]. Therefore, the studied location in the Dahomey gap differs from the ecologies of north and south guinea savanna of West Africa. Indeed, the studied zone was described as a costal savanna [22] representing a marginal zone of West Africa, which was named the Dahomey gap [23]. Therefore, this particularity could have induced differences in weed assemblages compared to the others savanna ecologies. Hence, our analyses provide additional knowledge of weed occurrence in rice growing agro-ecologies of West Africa.

The studied ecology was also characterized by a landscape of a wide plateau with depressions instead of a hydrographic network as described by Raunet [24] on the crystalline basement of West Africa. However, the trends of variation in soil nutrients were the same along the toposequence of *terre de barre* as described elsewhere [25]: divalent cations concentrations decreased from the summit to the foot slope, while soil concentrations of monovalent cations increased. Therefore, the influence of soil parameters on weed species occurrence as revealed in our actual study can be considered for the entire Dahomey gap and the other ecologies of West Africa according to the rule of nonreplicated ecological study [15].

4.2. Weeds Control by Soil Fertility Management. The lowest total weed biomass was observed in the quadrats when *Cyperus* and *Imperata* were absent. This result attested that factors affecting the occurrence of these species can also be considered for the others weeds species. Therefore, our result provides an insight to deeper knowledge of the interactions of divers weed communities with soil. However, exceptions should be considered for *Richardia brasiliensis* (Ricbr) and *Dactyloctenium aegyptium* (Dacae) which were encountered in all the quadrats (Figure 1) indifferently to the density of *Cyperus* and *Imperata*.

No significant relationship was observed between the soil parameters studied and *Cyperus* spp. biomass (Table 2). However, Koné et al. [26] showed a decreased of *Cyperus* abundance with the increasing soil Mg concentration. Indeed, our study revealed some implications of this nutrient (Mg) in *Cyperus* occurrence through the soil balance of K and Mg, excepted in the FS position (Table 4). Application of K fertilizer might be able to increase soil K : Mg ratio and decrease *Cyperus* abundance at the SUM, while supplying Mg might induce the same effect on *Cyperus* occurrence at the US and MS positions by altering the Ca : Mg ratio. Therefore, K or Mg amendments are required for depressing *Cyperus* occurrence according to topographic positions. Indeed, soil balance in K : Mg and Ca : Mg can affect not only K and Ca availability to plant but also P as observed by Yates [27]. Thus, it appears that *Cyperus* occurrence is more related to imbalanced ratio of nutrients in soil rather than the depletion effect of sole nutrient content.

Table 4: Pearson correlation values (R) and its probabilities (P) between *Cyperus* spp. and *Imperata Cylindrica* and soil different ratios in K : Mg and Ca : Mg at each topographic position.

		Correlation (R) and probability value (P)			
		Cyperus spp.		*Imperata Cylindrica*	
		R	P	R	P
K : Mg	SUM	−0.703	0.0002	0.397	0.021
	US	0.853	<0.0001	0.482	0.007
	MS	0.956	<0.0001	−0.338	0.032
	FS	0.273	0.290	0.378	0.034
Ca : Mg	SUM	0.843	<0.0001	−0.231	0.195
	US	0.839	<0.0001	0.066	0.729
	MS	0.822	<0.0001	−0.839	<0.0001
	FS	−0.094	0.719	−0.743	<0.0001

SUM: Summit; US: upper slope; MS: middle slope; FS: foot slope.

I. cylindrica occurrence was significantly influenced by soil Fe, Ca and K concentrations with less importance to soil particle sizes (Table 2). This result restricts the assertion made by Andreasen and Streibig [28] concerning the influence of soil texture on weed occurrence. Furthermore, the influence of soil nutrients was confirmed partially according to topographic positions. Highest soil K concentration was associated with high density of *Imperata* at the uphill position (SUM and US). Instead of reducing soil K concentration for depressing the density of *Imperata*, management strategy must focus on reduction of K : Mg by supplying Mg compound as consequence of Pearson correlation value observed in Table 4. *Imperata* density can also decrease at the downhill position with the decrease or increase of soil Ca concentration at the MS and the foot slope positions, respectively. However, no consistent management of soil Ca can be drawn from our study regarding the contrasts observed in Tables 3 and 4. Further investigations should also focus on K : Ca: Mg or [(Ca + Mg) : K] ratio for improving knowledge of the interaction between Ca and *Imperata*. Up to now, our study has improved knowledge of the effect of soil nutrients balance on weed occurrence as mentioned by the Midwest Organic and stainable Education Service (MOSES) [29].

4.3. Indicators of Soil Degradation in the Environment. The study revealed that highest soil Fe concentrations at the Hillside (US and MS) were also associated with a low density of *Imperata*. Otherwise, Fe leaching as observed in degraded soil [30] may be favorable to *Imperata* occurrence depending on topographic positions. Low soil K (0.03–0.08 cmol kg^{-1}) concentrations observed at the US position reinforced (Table 3) this assertion. Indeed, low K concentrations in soils of Africa occur generally in degraded soils according to Juo and Grimme [31]. Therefore, our finding confirms the fact that *Imperata* is a bioindicator of degraded soil as propounded by Scherr and Yadav [32].

The leaching of soil K and Mg leads to impoverishment of soil in these nutrients, justifying their requirement for the control of *Cyperus* spp. occurrence, especially by changing soil nutrient balance. Thus, soil chemical degradation can also induce *Cyperus* spp. occurrence and likewise for *Imperata*. In the Philippines, *Imperata cylindrica* and *Cyperus compressus* were observed in strongly weathered soil [33] corroborating our analysis and suggesting that soil organic amendment can reduce the invasion of these species, especially for Cyperus [26]. In the context of land management, we can recommend further study of fallowing or the cultivation of cover crops on *Cyperus* spp. and *Imperata* occurrences on Acrisols. These practices might be able to avoid soil degradation [34], restricting *Cyperus* and *Imperata* invasions.

Most of the knowledge of upland soil chemical degradation processes is related to nutrient depletion [35, 36]. Nutrient ratios have been investigated less frequently. Except for soil C (1.09–1.71%) and N (0.05–0.08%) concentrations and K (0.1 cmol kg^{-1}) concentrations at certain levels of significance, the studied soil had high nutrient concentrations, especially for P (8–26.4 ppm) and Na that reached 0.55 cmol kg^{-1} (Table 1). But rice yield can drop to 0.26 tha^{-1} even for improved varieties with a potential yield of 4-5 tha^{-1}, as a consequence of mineral imbalances, particularly C : N, Ca : Mg and K : Mg [23]. Regarding yield reduction as an indicator of agricultural soil degradation [32], we deduce that unbalanced soil nutrients in the studied area are likely to contribute. These characteristics (nutrient ratios) of soil were also involved in rice P-nutrition in an acid Ferralsol of Nigeria [37]. More investigations for understanding the effects of nutrient ratios in soils are required in tropical ecologies for improvement of agricultural land use, weed management, and restoration of degraded soils.

Our results showed association of high density of *Imperata* to *Commelina erecta* and *Richardia brasiliensis*. Finally, *Imperata*, *Cyperus*, *Commelina*, and *Richardia* can be considered as indicators of degraded Acrisols in the studied environment. The importance of soil exchangeable cation concentrations (Ca, Mg, Fe, and K) and the ratios of Ca : Mg and K : Mg for weeds occurrence in the Dahomey gap, and West African ecosystems by extension, confirms the work done by Udoh et al. [12] citing the importance of soil C, N, Zn, and Mn contents.

5. Conclusion

Soil parameters have influence the occurrence of weeds according to topographic positions, especially for *Cyperus* spp. and *Imperata Cylindrica*. However, the relationship with *Cyperus* spp. was less pronounced than with *Imperata Cylindrica*.

Soil balance, and in particular K : Mg and Ca : Mg ratios, were the main factors affecting the occurrence of these weeds in the studied ecosystem. Applying Mg and/or K fertilizers might be employed to change these soil characteristics to reduce *Imperata* and Cyperus invasions. Soil Fe concentration also influenced *Imperata* occurrence. It is suggested that Cyperus and *Imperata* occurrences prevailed in degraded soil for which they can be used as indicators, along with *Commelina* and *Richardia*. To some extent, our finding can be extended to other West African ecosystems.

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