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Assessment of Weeds of Cassava and Farmers' Management Practices in Nigeria

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Editor's Notes

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Résumé

Evaluation des mauvaises herbes dans la culture du manioc et pratiques de gestion des agriculteurs au Nigéria

La concurrence des mauvaises herbes est un obstacle à la rentabilité de la production du manioc. La connaissance des espèces de mauvaises herbes qui affectent négativement la productivité du manioc est essentielle pour une gestion efficace. Une étude a été conduite entre mai et juin 2014 et 2015 pour évaluer les mauvaises herbes dans 200 exploitations agricoles de manioc, dans trois zones agroécologiques au Nigeria. L'Analyse des Correspondances Détendancées (ACD) a permis d'identifier quatre groupes distincts illustrant la variation des espèces de mauvaises herbes parmi les zones agroécologiques. Le pH du sol et la teneur en limon, la durée des jachères, la méthode de culture et la méthode de gestion des mauvaises herbes ont contribué à la variation de la composition des espèces. L'évaluation par les agriculteurs et sur le terrain ont identifié Euphorbia heterophylla, Imperata cylindrica, Aspilia africana, Panicum maximum, Chromolaena odorata, Commelina benghalensis, Digitaria horizontalis, et Rottboellia cochinchinensis comme principales mauvaises herbes du manioc. La gestion de ces mauvaises herbes par les paysans varie à travers les zones, suggérant ainsi que les stratégies de gestion de ces mauvaises herbes devraient être axées sur les zones écologiques. Dans la zone forestière humide, le désherbage à la houe (51,2%) et à la machette (43,0%) étaient les principales méthodes de contrôle. L'utilisation d'herbicides était élevée dans le sud de la savane guinéenne et modérée dans la savane dérivée. L'éducation afin d'accroitre la connaissance des agriculteurs sur la problématique des mauvaises herbes et l'amélioration de leur choix à la fois sur les herbicides appropriés et leur utilisation sans risque est essentielle pour une gestion efficace des mauvaises herbes dans la culture du manioc.

Abstract

Competition from weeds is an obstacle to profitable cassava production. Knowledge of weed species negatively affecting productivity is essential for effective management. A field evaluation of weeds and management practices was conducted between May and June in 2014 and 2015 in 200 cassava farms in three agroecologies in Nigeria. Detrended Correspondence Analysis identified four distinct clusters depicting variation in weed species composition among the agroecologies. Soil pH and silt content, fallow length, cultivation method, and weed management method contributed to the variation in species composition. Farmers and field evaluations identified Euphorbia heterophylla, Imperata cylindrica, Aspilia africana, Panicum maximum, Chromolaena odorata, Commelina benghalensis, Digitaria horizontalis, and Rottboellia cochinchinensis as major problem weeds in cassava. Farmers' management of these weeds varied across zones, suggesting that weed management strategies in cassava should be focused on ecological zones. In the Humid forest, hoe-weeding (51.2%) and slashing (43.0%) with machetes were the predominant methods of control. Herbicide use was high in the Southern Guinea Savanna and medium to high in the Derived Savanna (26.3-42.2%). Education to increase farmers' knowledge of the problematic of weeds and to improve both their choice of appropriate herbicides and their safe use is critical to effective and efficient weed management in cassava.

Index by keyword : weed species composition, cassava weeds, cassava farm size, farmer weed management, Nigeria

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Introduction

Cassava is a major staple crop that feeds the majority of Nigerians as well as providing a source of income to many resource-poor farmers. Nigeria is a global leader in cassava with about 54 million t produced on 3.8 million ha (10). Abia, Benue, Ogun, and Oyo States within Nigeria are among the major cassava growers with an estimated 9.3 million t (19) of production. Cassava is highly susceptible to weed infestation resulting in competition especially from perennial weeds because of its initial slow growth rate, wide plant spacing, and the long maturity period of between 12 and 18 months (6, 13). Environments where cassava is growing tend to be dominated by perennial weed species such as *Imperata cylindrica, Chromolaena odorata, Panicum maximum, Cyperus rotundus*, and *Mimosa invisa*, which have been reported to constitute problems in the crop (18, 23).

Weed infestation on cassava farms is a major factor contributing to low crop yield and inflicts untold hardship on smallholder farmers due to numerous hoe weedings during the season requiring family or paid labor. Hoe weeding requires 50 to 80% of the total labor budget in production and as many as 200 to 500 hours of labor ha^{-1}, mostly done by women and children, to prevent economic root losses (9). Uncontrolled weed infestation throughout the life cycle of cassava have been reported to cause losses in root yield of 40 - 90% (4, 6, 28). Full-season weed competition from *I. cylindrica* and *Tithonia diversifolia* can cause root yield reduction of 70 - 80% depending on the cropping system (i.e. intercrop, monocrop) and cultivar grown (3, 6). On many smallholder farms, the first hand weeding is often delayed for up to two months after planting, resulting in a reduction of cassava root yield by 20 to 50% (2, 8). Timely weeding is often not done owing to competing household labor demands and the drudgery associated with hoe weeding.

In Nigeria, the necessity for land clearing and weed control are major factors influencing acreage of land under cassava cultivation (21). Hand weeding with a simple hand-held hoe and machete is the predominant weed control method on smallholder farms. This method is expensive and requires proper timing to reduce weed competition. Generally, Nigerian farmers weed cassava three times in the first 3 to 4 months of growth but if perennial weeds, such as *I. cylindrica,* are predominant additional hoe weeding (>3) may be required. Akobundu (2) reported that about one-third of farmers' time on cassava farms is spent on hoe weeding; the traditional method of weed control. However, many farmers are interested in herbicides for weed control or have started using them in cassava to reduce the need for expensive hoe weeding (29).

The impact of weeds may differ among crops and locations as some weeds may be location-specific and/or more competitive in a particular crop. Weed spectra also vary in occurrence, diversity, distribution, and infestation at various locations and in different seasons (22, 27). For effective weed management in cassava production, there is a need for accurate information on weed species diversity, frequency of occurrence, competitive ability and abundance which will enable improved technologies with proper timing of control to be implemented to reduce weed competition. Such vital information is scarce for cassava producing areas within Nigeria.

This study was designed to provide science-based knowledge on the diversity of weeds in cassava systems in Nigeria. Furthermore, there is little systematic information on farmers' current management practices upon which to build effective, practical, and profitable options for weed control. The objective of this study was to identify the major weeds, determine their level of occurrence, and farmers' crop and weed management practices. We hypothesize that occurrence and diversity of weed species are correlated with agroecological zones and farm management practices.

Methodology

Sampling procedure

A field survey of weeds of cassava in farmers' fields was conducted between May and June in 2014 and 2015 in Abia, Benue, Ogun, and Oyo States which are representative of three agroecological zones (Humid Forest: HF, Derived savanna: DS, Southern Guinea savanna: SGS) where cassava is grown in Nigeria. In each State, 50% of the Local Government Areas (LGAs) from major cassava producing areas were sampled. The LGAs in each State were selected using local State maps and in consultation with the Agricultural Development Program (ADP) officials (Table 1). In each LGA, five major cassava producing communities were identified and a one-year-old cassava farm was selected randomly from each community for sampling. Five quadrats measuring 1 × 1 m were sampled systematically in each cassava farm along two intercepting diagonals with one of the quadrats placed at the interception of the two transects. Quadrats along diagonal transects were placed 10 m away from each other. In each quadrat all weed species were identified by a trained taxonomist and counted. Soil samples were taken at a depth of 0 to 10 cm in each quadrat. Soil samples were bulked to form one sample for each farm and was used to determine soil fertility and physical properties. The position of each farm sampled was recorded using a Global Positioning System (GPS).

In each LGA, a questionnaire was administered to the five farmers in each community whose farms were sampled to obtain information on history of cultivation, methods of land preparation, fertilizer application, troublesome weeds, and weed management practices.

Table 1: Survey sites in Abia, Benue, Ogun, and Oyo States in 2014.

State	AEZ†	Number of farms sampled	Local Government Area
Abia	HF	45	Bende, Ikwuano, Isuikwuato, Ohafia, Umuahia North, Umuahia South, Osisioma, Ukwa West, Umuneochi
Benue	SGS	60	Vandeikya, Ushongo, Kwande, Konshisha, Gwer-East, Katsina-Ala, Ohimini, Okpokwu, Otukpo, Gboko, Makurdi, Ado
Ogun	DS	45	Remo North, Obafemi Owode, Odeda, Yewa South, Abeokuta North, Abeokuta South, Ewekoro, Ikenne, Odogbolu, Ogun Water Side
Oyo	DS	50	Akinyele, Ido, Iseyin, Afijio, Oyo West, Saki East, Ibarapa East, Atisbo, Itesiwaju, Surulere

† AEZ: Agroecological zone (HF: Humid forest, SGS: Southern Guinea savanna, DS: Derived savanna)

Statistical analysis

Species richness was assessed as the number of different species encountered in each cassava farm and agroecological zone. Weed species diversity across zones was measured by using the Shannon-Weiner diversity index (25). This is given by the equation I:

$$H' = -\sum_{i=1}^{s} pi \in pi \qquad \text{I}$$

Where, s = the number of species at each site, ni = number of individuals in species i, N = the total number of all individuals, Pi = the relative abundance of each species, calculated as ni / N

Detrended Correspondence Analysis (DCA) was used to assess variation in species composition among cassava farms across agroecological zones; Canonical Correspondence Analysis (CCA) was used to relate weed species abundance to measured soil nutrients and farmers' weed management practices in CANOCO 5.0 (26). Relative Importance Value (RIV) of each weed species in each cassava farm was used for the DCA and CCA. In each farm RIV measures the overall significance of species and was calculated for each species as Relative frequency + Relative density divided by 2. Monte Carlo permutation tests were performed to test for significance of the first eigenvalue and the trace statistics of both the DCA and CCA (26). Analysis of variance (ANOVA) was used to test differences in species richness and diversity within and among zones using the Mixed Model Procedure in SAS (24). The percentage frequency of respondents was calculated using the Frequency Procedure in SAS (24) to determine the history of cultivation, methods of land preparation, fertilizer application, problem weeds, and management practices.

Results and discussion

Weed species composition and distribution

A total of 153 weed species belonging to 32 families were identified in cassava farms across the four States studied. Weed species richness was significantly lower in Abia State compared with the other States (Table 2). There was a significant difference in weed species diversity between cassava farms in Abia and those in Benue and Oyo States. Weed species diversity in cassava farms in Abia and Ogun States was similar.

In each State, species richness varied among LGAs (Figure 1). In Abia State, species richness and diversity were highest in Ikwuano followed by Umuahia South (Figure 1A and 1E). In Benue State, there were more weed species in Katsina-Ala, Gboko, Ushongo, and Gboko than in the other LGAs (Figure 2B). In this State, species diversity in cassava farms was significantly higher at Ushongo compared with the other LGAs except Katsina-Ala, Vandelkya, Kwande, and Okpokwu. In Ogun State, cassava farms in Odeda and Abeokuta South had a similar number of species which was similar to the number recorded in farms in the other LGAs (Figure 1C). Cassava farms in Abeokuta North had the lowest species diversity (Figure 1G). In Oyo State, weed species richness was significantly higher in Akinyele compared with Atisbo and Iseyin LGAs (Figure 1D). Weed species diversity was lowest at Iseyin LGA (Figure 1H).

Four distinct clusters (A, B, C, D) were identified by DCA depicting variation in weed species composition among farms in the three agoecological zones with a clear separation between farms in the DS (Ogun and Oyo) and the HF (Abia) agroecologies on the first ordination axis (Figure 2). There was a clear separation of farms in the DS from those in the SGS (Benue) on the second ordination axis. The first and second axes of the DCA explained only 18.8% of the total variation in the weed species data (eigenvalue for axis 1 = 0.46; axis 2 = 0.25, total inertia = 3.933). The low variance explained by the first two axes may be attributed to the presence of rear species in the data matrix which were not down-weighted in the analysis. Within the SGS zone, cassava farms stretched vertically along axis 2. Three farms in this zone located in Katsina-Ala, Ushongo, and Gboko LGAs in the northern part of Benue did not fit the designated agroecology and were located close to sites in Shaki and Atisbo LGAs in Oyo State in the DS. Although Oyo State was generally classified in the DS zone, Shaki and Atisbo LGAs have characteristics of the SGS zone, such as high temperatures and a unimodal rainfall pattern similar to that of Benue State. The cassava farms in the SGS (Benue State) which were located close to clusters in the DS zone (Oyo State) have soils similar in alkalinity to some farms in Shaki and Atisbo in Oyo State. Across the SGS zone, the 10 most important weed species in cassava farms in a decreasing order of importance were *T. procumbens, E. heterophylla, I. cylindrica, R. cochinchinensis, P. orbiculare, E. hirta, A. conyzoides, D. horizontalis, Pennisetum pedicellatum, and P. maximum* (Table 2). Clusters A and B representing Ogun and Oyo States in the DS zone lie close to each other, indicating closeness in weed species composition. Although farms in clusters A, B, and C have many species in common, the species vary in importance. In Ogun State, the most important species identified in cassava farms (Table 2) were *T. procumbens*, *Aspilia africana*, *C. odorata, Commelina diffusa, D. horizontalis, C. benghalensis, B. deflexa, and C. mucunoides.*

Most species were ubiquitous, occurring in all agroecological zones, but varied in abundance within and across zones. In both the DS (Ogun and Oyo States) and SGS (Benue State) agroecological zones, *T. procumbens* was the most important species compared to the HF zone where *A. conyzoides* ranked as the most important species. In the DS and SGS zones, *T. procumbens* occurred in high densities with frequency of occurrence ranging from 60 to 100%. Chikoye *et al.* (5) identified *T. procumbens* as the most abundant weed species in cassava-based systems in the Dry Savanna, Mountain and Transition Forests ecological zones in both seasons, dry (December to February) and wet (June to August). In this study, *T. procumbens* was abundant in all areas of the ecological zones where farmers use paraquat and glyphosate repeatedly to control weeds in cassava. In Benue State, Ibraham *et al.* (15) reported heavy infestation of *T. procumbens* in cassava farms treated with flazifop-p-butyl for *I. cylindrica* control. Some studies (11, 12, 17) reported glyphosate tolerance in *T. procumbens*. Galon *et al.* (11) noted that 75% of glyphosate applied on *T. procumbens* remained in the leaf of the plant with translocation to the floral buds. In Western Australia, some biotypes of *T. procumbens* have shown resistance to glyphosate (12). As shown by Doll *et al.* (7) where plant density of 340, 000 plants/ha occurred in cassava farms in Columbia, *T. procumbens* possesses a serious challenge to cassava production especially at the early initial slow growth phase of the crop owing to high densities.

Canonical Correspondence Analysis (CCA) grouped cassava farms by agroecological zones similar to the clusters depicted by DCA (Figure 3). The first axis of the CCA (eigenvalue = 0.42) explained 26.3% of the variation in the weed species data and 41% of the species environmental relations. The influence of environmental variables on species data on the first axis was significant (*F = 6.6980; P = 0.0020*). Soil pH (canonical coefficient = -0.6221), manual hoe weeding (canonical coefficient = 0.5739), fallow length (canonical coefficient = 0.5044), and use of glyphosate (canonical coefficient = -0.4839) were the most important variables on the first axis associated with the distribution of farms in the DS and HF zones along the first axis. The majority of cassava farms in the DS zone have alkaliphilic soils, low in Organic Carbon (%OC), Calcium (Ca), and Potassium (K) (Figure 3), and were associated with mechanical cultivation (MechCult). In this zone, farmers plow their fields twice with tractor-drawn plows and plant cassava on the flat. But where cassava is ridge-planted, ridges are made manually with hoes. In this agroecological zone, cassava farms were associated with herbicide use and a combination of herbicides and manual hoe weeding (HerbHw) as methods of weed control. Atrazine and paraquat were the major herbicides used in this zone. Atrazine is used pre-emergence and paraquat and manual hoe weeding are used post-emergence to control weeds in the later growth stage of cassava. In addition to atrazine and paraquat, farms in this zone were associated with glyphosate. Some of the farmers apply glyphosate to perennial weeds such as *P. maximum* to kill the weeds before tillage.

Axis 2 of the CCA has an eigenvalue of 0.224 and explains 15.9% of the variation in the data and 41.0% of the species environmental relations. The overall influence of environmental variables on species data was significant (*F = 1.7637; P = 0.0020*). Mechanical cultivation [MechCult] (canonical coefficient = -0.5124), Ca (canonical coefficient = 0.3402), and soil silt content (canonical coefficient = 0.0.2872) were the most important environmental variables on the second axis of the CCA explaining the variation on species data (Figure 3). The soils in surveyed farms in the SGS zone were mostly silty, low in Nitrogen (N), available Phosphorus (P), and Magnesium (Mg). Farms in this zone were associated with glyphosate and farmers' use of glyphosate here for weed control in cassava is high compared to Abia State. In the HF zone, cassava farms were associated with acid and sandy soils with higher P and Mg contents than farms in the DS and SGS zones. Fallow length and hoe weeding were clearly associated with cassava production in the HF zone where the crop is cultivated from fields that have been fallowed. Farmers practice slash and burn farming systems where fields are fallowed for 2 to 3 years before cultivation. Manual weed control is the predominant method with minimal herbicide use. In general, all measured environmental variables together explained 38.8% of the total variation in the data, suggesting that other factors, such as cropping history and weed management practices, may have contributed to the variation in weed species composition.

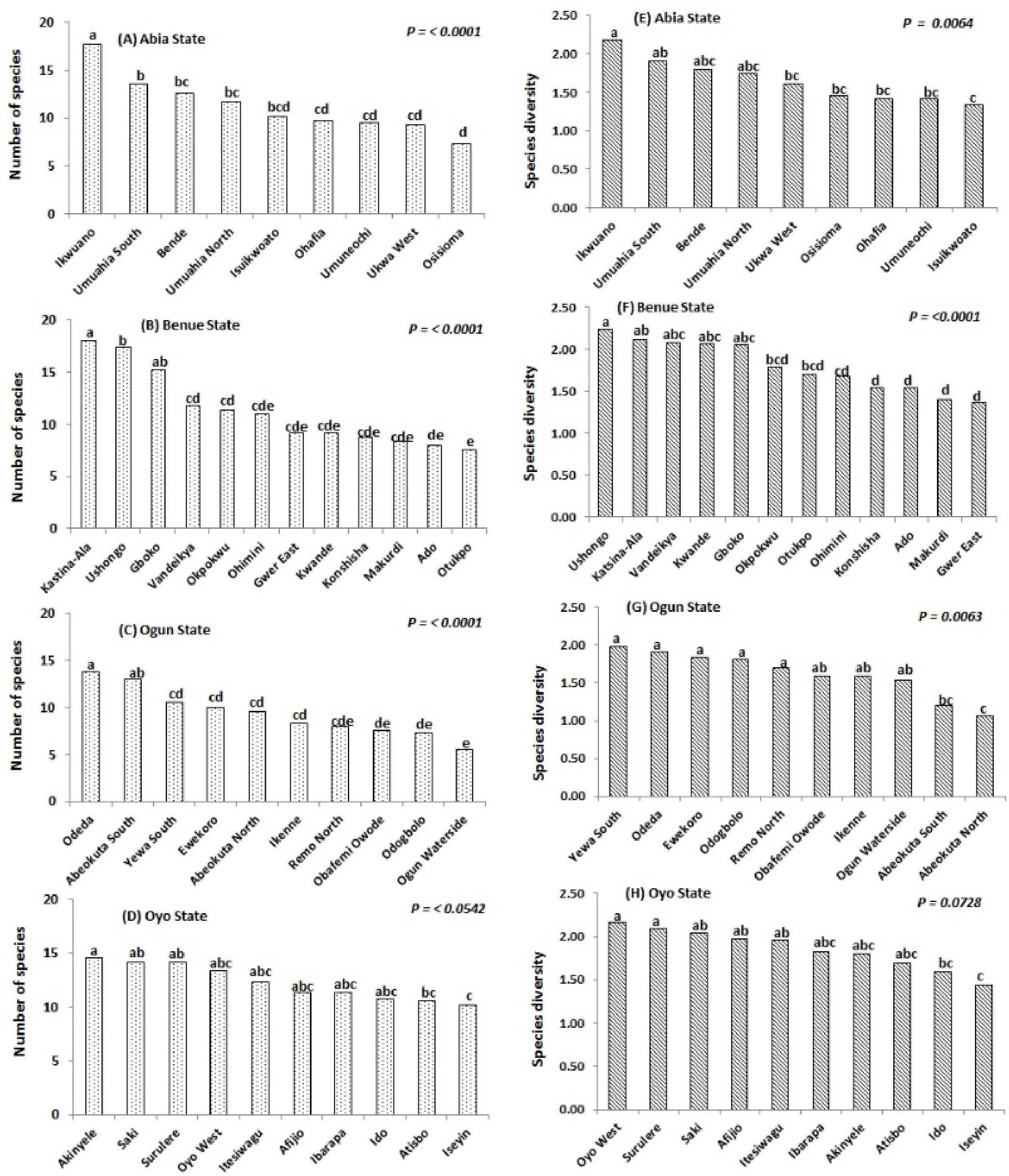

Figure 1: Weed species richness in cassava farms in different LGAs in Abia, Benue, Ogun and Oyo States in 2014 sampling.

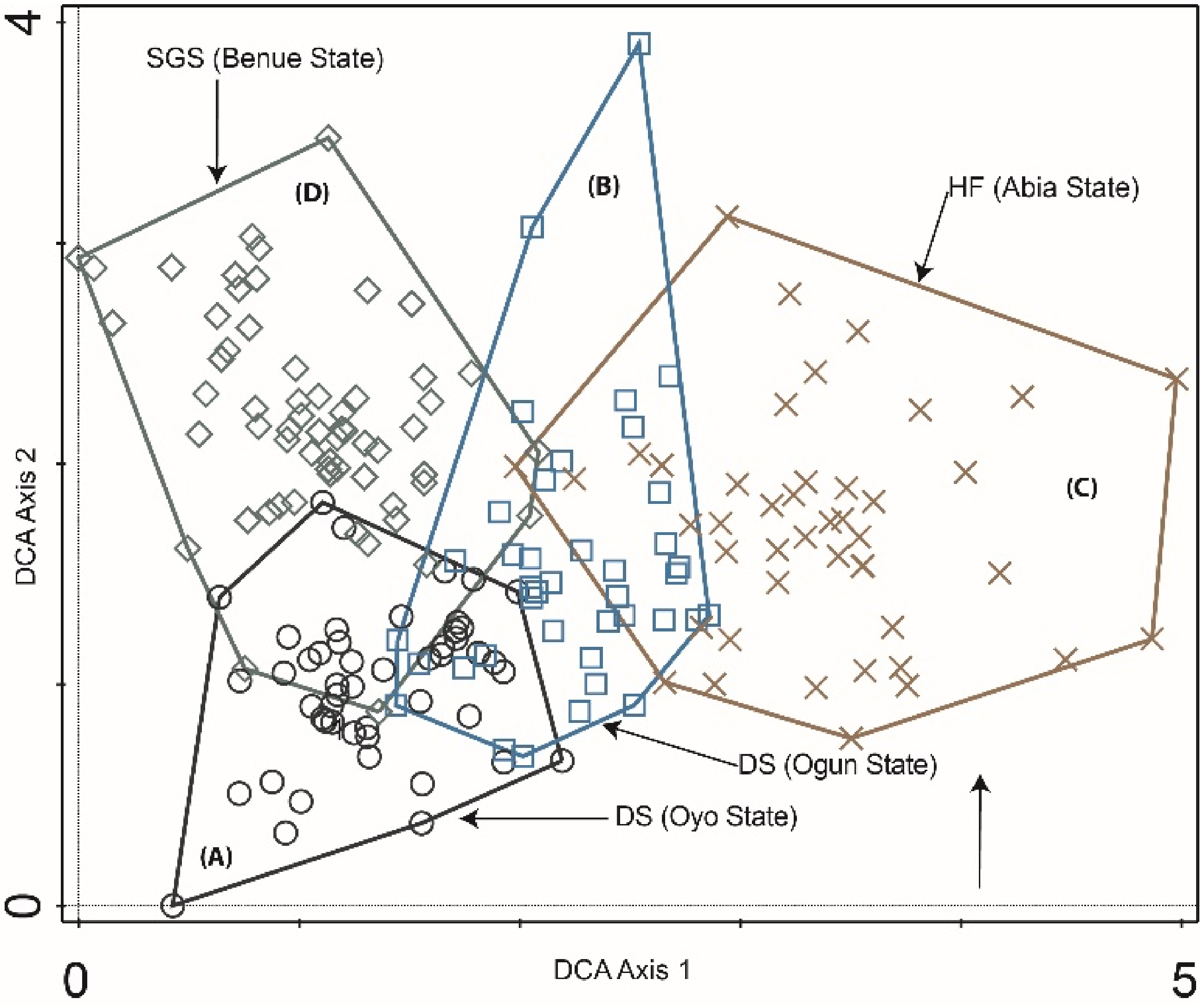

Figure 2: DCA ordination of 195 cassava farms from four States representing three agroecological zones [Humid Forest: HF (x), Derived Savana: DS (Ogun = □ ; Oyo = o), Southern Guinea Savanna: SGS (◇)] in Nigeria.

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Table 2: Species richness, Shannon diversity, and 30 most important weed species in cassava farms in four States, Abia (HF), Ogun (DS), Oyo (DS), and Benue (SGS) in 2014. Species ranking was based on Relative Importance Value index.

Attributes	Abia State (HF)	Ogun State (DS)	Oyo State (DS)	Benue State (SGS)	
Species richness	75a	64b	86a	74a	
Shannon diversity	1.66bc	1.62c	1.86a	1.80ab	Importance value ranking
Most common weed species	*Ageratum conyzoides* (18.41)	*Tridax procumbens* (19.69)	*Tridax procumbens* (21.79)	*Tridax procumbens* (22.03)	1
	Cyperus rotundus (9.65)	*Aspila africana* (12.58)	*Imperata cylindrica* (16.65)	*Euphorbia heterophylla* (19.53)	2
	Aspilia africana (9.54)	*Chromolaena odorata* (12.42)	*Euphorbia heterophylla* (14.01)	*Imperata cylindrica* (18.84)	3
	Platostoma africanum (9.30)	*Commelina diffusa* (12.34)	*Mitracarpus villosus* (9.12)	*Rottboellia cochinchinensis* (14.57)	4
	Commelina benghalensis (8.30)	*Digitaria horizontalis* (11.58)	*Brachiaria deflexa* (7.34)	*Paspalum orbiculare* (10.21)	5

Chromolaena odorata (6.67)	*Spigelia anthelmia* (10.08)	*Digitaria horizontalis* (6.63)	*Euphorbia hirta* (8.15)	6
Panicum maximum(6.38)	*Brachiaria deflexa* (9.98)	*Commelina benghalensis* (5.63)	*Ageratum conyzoides* (6.89)	7
Calopogonium mucunoides (6.31)	*Calopogonium mucunoides* (9.29)	*Rottboellia cochinchinensis* (5.33)	*Digitaria horizontalis* (5.95)	8
Axonopus compressus (6.12)	*Commelina benghalensis* (8.65)	*Phyllantus amarus* (5.03)	*Pennisetum pedicellatum* (5.84)	9
Mitracarpus villosus (5.86)	*Talinum triangulare* (8.57)	Sedge (4.83)	*Panicum maximum* (5.34)	10
Mimosa invisa (5.85)	*Mariscus alternifolius* (6.72)	*Euphorbia hirta* (4.76)	*Phyllantus amarus* (4.98)	11
Digitaria horizontalis (5.22)	*Perotis indica* (6.25)	*Brachiaria lata* (3.98)	*Cyperus rotundus* (4.80)	12
Urena lobata (4.96)	*Phyllanthus amarus* (5.88)	*Pennisetum polystachion* (3.90)	*Acanthospermum hispidum* (4.48)	13
Oldenlandia corymbosa (4.68)	*Panicum maximum* (5.83)	*Passiflora foetida* (3.75)	*Spigelia anthelmia* (4.36)	14
Croton hirtus (4.27)	*Andropogon tectorum* (5.23)	*Chromolaena odorata* (3.74)	*Setaria pumila* (34.21)	15
Mariscus alternifolius (4.03)	*Rottboellia cochinchinensis* (4.89)	*Mariscus alternifolius* (3.63)	*Andropogon tectorium* (3.91)	16
Euphorbia heterophylla (3.58)	*Euphorbia heterophylla* (4.20)	*Dactyloctenium aegyptium* (3.45)	*Daniellia oliveri* (2.97)	17
Kyllinga erecta (3.37)	*Cyperus esculentus* (3.73)	*Panicum maximum* (3.38)	*Hyptis suaveolens* (2.88)	18
Centrosema pubescens (3.36)	*Sida acuta* (2.92)	*Talinum triangulare* (3.32)	*Commelina diffusa* (2.77)	19
Achyranthes aspera (3.35)	*Ageratum conyzoides* (2.83)	*Sida acuta* (3.18)	*Tephrosia bracteolata* (2.36)	20
Ipomoea involucrata (3.30)	*Imperata cylindrica* (2.26)	*Borreria diffusa* (2.96)	*Cyperus haspan* (2.19)	21
Vernonia cinerea (3.30)	*Passiflora foetida* (2.16)	*Paspalum orbiculare* (2.40)	*Desmodium scorpiurus* (2.17)	22
Pteridium acquilium (3.23)	*Sclerocarpus africanus* (2.12)	*Desmodium scorpiurus* (2.24)	*Brachiaria deflexa* (2.12)	23
Imperata cylindrica (3.19)	*Acroceras zizanioides* (2.04)	*Tephrosia elegans* (2.08)	*Urena lobata* (2.10)	24
Cynodon dactylon (3.13)	*Daniellia oliveri* (1.87)	*Calopogonium mucunoides* (2.08)	*Oldenlandia corymbosa* (2.07)	25
Peperomia pellucida (3.10)	*Mitracarpus villosus* (1.80)	*Cleome viscosa* (1.71)	*Nauclea latifolia* (1.96)	26

Alternanthera sessilis (3.01)	*Mucuna* sp, (1.50)	*Acroceras zizanioides* (1.64)	*Gomphren a celosioides* (1.90)	27
Ludwigia sp (2.52)	*Synedrella nodiflora* (1.46)	*Commelina diffusa* (1.58)	*Sida corymbosa* (1.77)	28
Spigelia anthelmia (2.48)	*Cyperus rotundus* (1.34)	*Tithonia diversifolia* (1.49)	*Commelina benghalensis* (1.71)	29
Richardia brasiliensis (2.46)	*Stylosanthes* sp (1.16)	*Indigofera hirsuta* (1.45)	*Brachiaria lata* (1.57)	30

Means in the same row with the same letter are not significantly different. HF = Humid Forest, DS = Derived savanna, SGS = Southern Guinea savanna

Table 3: Percentage distribution of respondents from four cassava growing States in Nigeria according to ten most problematic weed species identified by farmers in cassava fields in 2014. Values in parenthesis are percentage responses.

	Benue State †	**Ogun** State †	**Oyo** State †	**Abia** State †
1	*Euphorbia heterophylla* (25.3%)	*Panicum maximum* (15.2%)	*Imperata cylindrica* (13.9%)	*Ageratum conyzoides* (11.8%)
2	*Imperata cylindrica* (24.3%)	*Chromolaena odorata* (10.1%)	*Panicum maximum* (13.9%)	*Aspilia africana* (6.6%)
3	*Tridax procumbens* (9.1%)	*Commelina diffusa* (8.9%)	*Dactylotenium aegyptium* (6.9%)	*Cyperus rotundus* (6.6%)
4	*Rottboellia cochinchinensis* (6.1%)	*Tridax procumbens* (7.6%)	*Digitaria horizontalis* (6.9%)	*Digitaria horizontalis* (5.3%)
5	*Commelina benghalensis* (6.1)	*Aspilia africana* (5.1%)	*Euphorbia heterophylla* (6.9%)	*Mitracarpus villosus* (5.3%)
6	*Paspalum orbiculare* (4.0%)	*Euphorbia heterophylla* (5.1%)	*Rottboellia cochinchinensis* (6.9%)	*Panicum maximum* (5.3%)
7	*Setaria pumila* (4.0%)	*Imperata cylindrica* (5.1%)	*Tridax procumbens* (6.9%)	*Chromolaena odorata* (4.0%)
8	*Cyperus rotundus* (3.0%)	*Sida acuta* (5.1%)	*Boerhavia diffusa* (6.9%)	*Richadis brasiliensis* (4.0%)
9	*Digitaria horizontalis* (3.0%)	*Digitaria horizontalis* (3.8%)	*Passiflora foetida* (6.9%)	*Urena lobata* (4.0%)
10	*Platostoma africanum* (2.6)	*Andropogon tectorum* (2.5%)	*Cynodon dactylon* (6.9%)	*Achyranthes aspera* (2.6%)
11	Others (12.5%)	Others (31.5%)	Others (17.0%)	Others (44.5%)

† Important weed species identified by farmers were also identified in field sampling.

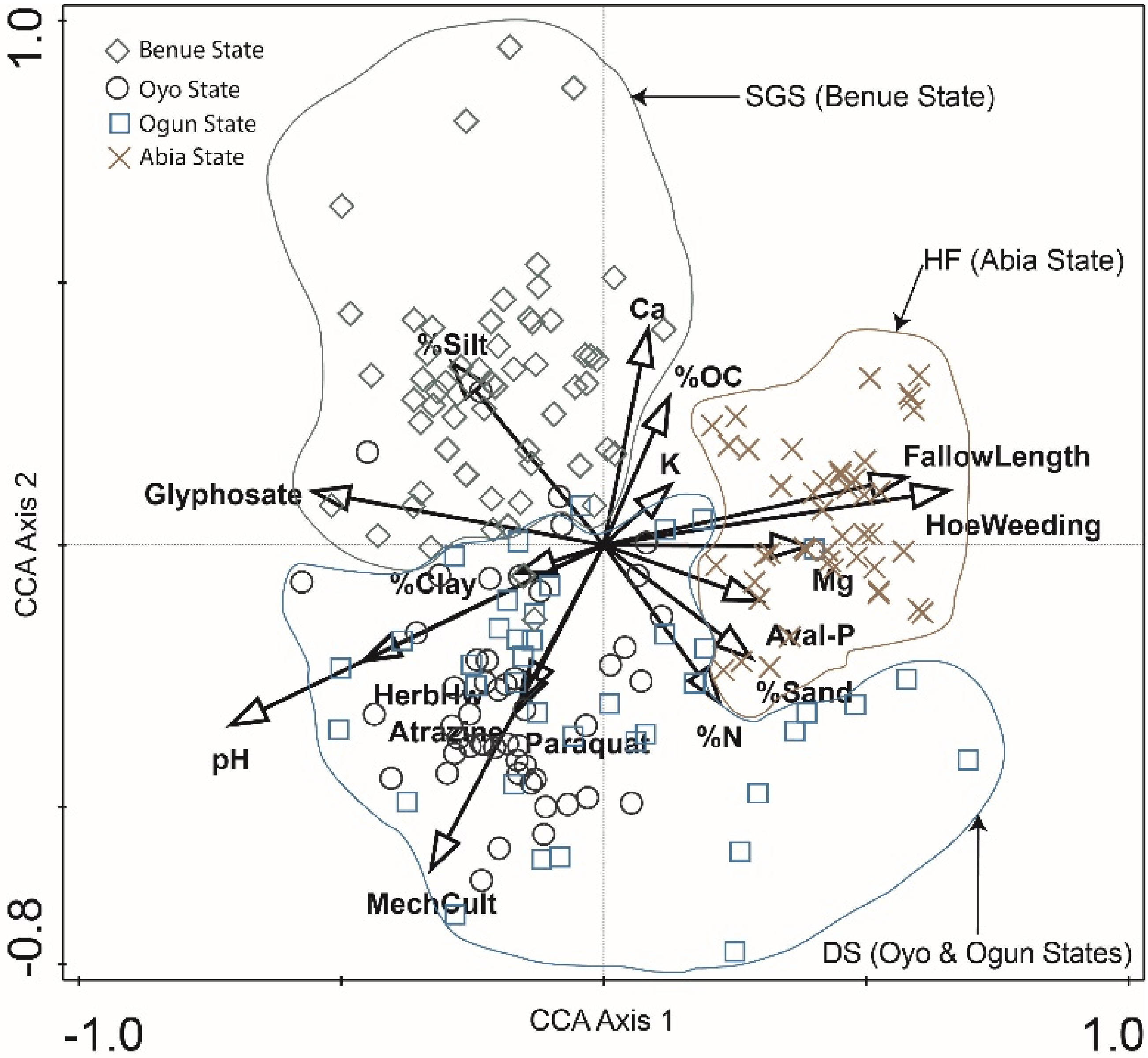

Figure 3: CCA ordination of weeds species sampled in 195 cassava farms from four States representing three agroecological zones [Humid Forest: HF (x), Derived Savana: DS (Ogun = □ ; Oyo = o), Southern Guinea Savanna: SGS (◇)] in Nigeria. Soil chemical and physical properties are represented by vectors where HerbHw = Herbicide application followed by supplementary hoe weeding, MechCult = Mechanical cultivation with tractor-drawn plow, FallawLength = Length of fallow before fields are cleared for planting, HoeWeeding = manual hoe weed control.

Characteristics of surveyed cassava farmers

Cassava farms varied in size among LGAs and ranged as follows; 0.20 - 15.6 ha in Benue, 0.20 - 50 ha in Ogun, 0.40 - 50 ha in Oyo, and 0.20 - 4.94 ha in Abia States, with corresponding average farm sizes of 2.6, 10.9, 4.0, and 0.36 ha, respectively. Overall, average farm size across the four States was 2.93 ha (n = 175). The majority of farmers in Benue (45.8%), Ogun (37.3%), and Abia (88.9%) States had farm sizes from 1.0 to 2.99 ha; in Oyo State, the majority (38.5%) had farm sizes from 3.0 to 5.99 ha. In Benue State, 20.8% of the farmers had farms < 1 ha while Ogun (21.0%) and Oyo (15.4%) States had farm sizes ≥ 9.0 ha. In all the States, most farmers had more than one cassava farm. The relatively higher percentage of respondents with farm sizes of 3.0 to 5.99 ha in Oyo State could be attributed to the influence of two major research institutes - International Institute of Tropical Agriculture (IITA) and the Institute of Agricultural Research and Training (IAR&T) - which have been disseminating technologies on production and processing. In the eastern and northern parts of the country where Abia and Benue States are located, land is highly valued as an asset, and access to land for large farms is often very difficult. Generally, farm holdings are small in Nigeria, because access to cultivatable land is often hindered by cultural constraints; and weed infestation and control limit the size of farm that smallholders can manage effectively.

Farmers in all study sites prepare land and make ridges or mounds for cassava planting either manually with simple tools such as machetes and hoes; mechanically, with tractors and tractor-mounted implements, or by a combination of both methods. The majority of farmers surveyed in Abia (100%), Benue (91.7%), and Ogun (68.9%) States prepare fields for planting with manual tools. In Oyo State, most farmers (59%) employ mechanical methods in preparing land for cassava cultivation. In Ogun and Oyo States, farmers employ a combination of manual method (hoe, machetes), and tractors with plows in land preparation. In Oyo State, the use of the tractor with a plow (57.5%) for land preparation was prevalent compared to the other States. Many of the farmers in Oyo (84.6%) and in Ogun (72%) States hire tractors and plowing implements from private sources. The numbers of operations farmers carry out during land preparation varied among the States. In Oyo State, where tractor usage is dominant, many farmers (92.9%) plow twice. Similarly in Ogun State, where tractors are also used in land preparation, 40.5% conduct more than three operations in land preparation. In Abia State, where hoes and machetes are the major tools for land preparation, more than three (64.5%) operations are carried out in preparing the land. The interval between each operation in land preparation is between 8 to 15 days in Benue (51.3%), Ogun (60.0%), and Oyo (47.8%) States; in Abia State where land preparation is predominantly manual, intervals between operations usually exceed 15 days (80%). In the study area, land preparation for cassava planting follows several stages such as initially removing the vegetation, plowing, harrowing in some cases, and ridging or mounding. These operations vary among States and agroecological zones. In the HF (Abia) zone where shifting cultivation is practiced, farmers usually cultivate fields after 3 - 5 years of fallow, with such fields dominated by woody perennial shrubs and trees. In this zone, farmers clear the vegetation with machetes, remove woody stems from shrubs and the trunks of trees, and allow twigs and other biomass to dry before burning. Where ridges are to be made, farmers remove shrubs and tree stumps before making ridges. Most farmers in this zone make mounds with hoes without stumping, and this may explain the high number of respondents that use manual methods of land preparation in Abia. In Ogun State, farmers slash and burn the initial vegetation before making ridges or mounds, but in areas where the vegetation is dominated by grasses or the fields are cultivated continuously, the majority of farmers plow the vegetation, and often fields are plowed twice without harrowing before ridges are made manually. This may explain the high percentage of farmers in Ogun State that carry out more than three operations in land preparation. The majority of the cassava growing areas in Benue State fall within the SGS zone with grasses dominating the vegetation. In this zone, glyphosate is used to kill existing vegetation before mounds or ridges are made for cassava planting (1).

Cassava is planted under rain-fed agriculture in the study area with farmers planting at the on-set of rainfall in each cropping season. Surveyed farmers planted cassava from March to November. In Benue State, farmers planted cassava between April and November with the majority of surveyed farmers planting in April (16.4%) and May (21.8%). In Ogun State, planting started in February and stretched to December. However, the majority of farmers planted in March (41.9%). In Oyo State, farmers planted cassava between April and November with peaks of planting in May (17.2%) and August (17.1%). In Abia State, the major peak of planting was in April (18.6%).

Farmers' use of fertilizer in cassava was low (15 to 20%) in Benue, Oyo, and Ogun States; it was higher in Abia State (44.2 %). In Abia State, most farmers used two fertilizer formulations of NPK [15:15:15] (46.7%) and [20:10:10] (46.7%). Most farmers in Oyo (85.7%) and in Ogun (50%) States used NPK [15:15:15]. However in Ogun State, farmers used NPK [20:10:10] (20%) as well as Urea, muriate of potash, and liquid fertilizer. In Benue State, most farmers used Urea (44%) and NPK [15:15:15] (33.3%). In this State, some farmers used granular NPK [20:10:10] and liquid fertilizer (11.1%) for each fertilizer type. The majority of the respondents in Benue (77.8%), Ogun (62.5%), Oyo (50.0%), and Abia (62.5%) States applied between 1 and 3 bags (50 kg/bag) of fertilizer per ha of cassava farm. The quantity of fertilizer applied by farmers was below the recommended rate of 450 to 600 kg (equivalent to 9-12 bags) per ha of NPK [15-15-15] (16). The limited use of fertilizer by cassava farmers could be attributed to the non-availability and high cost of the product as well as the farmers' perception that the crop does well even on marginal lands. Most farmers that use fertilizer in Nigeria do so when cassava is being intercropped with maize

Some studies have shown that on poor soils cassava responds to fertilizer (14). This was demonstrated in a series of fertilizer trials conducted in West Africa (Ghana and Nigeria), Latin America (Brazil), and Asia. In this study (14), out of 477 demonstration trials in West Africa, the average root yield increased from 12.3 t/ha in the control treatment to 18.3 t/ha with fertilizer, resulting in 49% yield gain. Wilson (30) reported a significant increase in root yield with 200 and 400 kg/ha NPK fertilizer on an acid inceptisol soil at Centeno in Trinidad and Tobago. The majority of farmers in Ogun (80.0%) and Abia (76.0%) States sourced fertilizer from government agencies; all farmers in Benue (100%) and 71.4% of farmers in Oyo State obtained fertilizer from private sources. Fertilizer could be more expensive from private sources when compared to that from government sources, mainly because of a subsidy. The majority of farmers (60 to 95.8%) in all the States apply fertilizer by placing it close to the plant. Most farmers in Ogun (77.8%) and Abia (62.5%) States applied fertilizer between 2 and 4 weeks after planting; in Benue State, farmers (33.3%) applied fertilizer in cassava farms after planting.

Farmers' identification of problem weeds was based on the farmers pulling the weeds they considered a problem and showing them to the enumerators or field personnel for identification. Altogether, farmers identified a total of 71 species they regarded as problem weeds in their farms in the four States surveyed. Thirty-four species were identified as problem weeds by farmers in Abia, 23 in Benue, 29 in Ogun, and 23 in Oyo States (Table 3). In general, the weeds identified by farmers as a problem were also the dominant weeds recorded during the survey.

Farmers' method of weed control varied among sites. Hoe-weeding, slashing with machetes, and use of herbicides were identified by respondents as methods of control in cassava. In Benue States, more farmers (51.2%) used herbicides rather than the hoe (47.6%) to control weeds in cassava. Odoemenem and Otanwa (20) reported that 68.9% of farmers sampled in 10 communities in Ohimini in Benue State used herbicides for weed control. A reversed trend was reported in Abia State where 51.2% of surveyed farmers control weeds by hoe-weeding and 43% by slashing with machetes, with only 5% using herbicides. In Oyo State, almost equal numbers of farmers used herbicides (42.2%) and hoe-weeding (48.4%). In Ogun State, 26.3 % of farmers used herbicides; 44.7% does slashing with Machetes, and 29% does hoe-weeding to control weeds.

Frequency of weed control by farmers varied among sites. Although up to five weeding operations were reported in two States (Ogun and Oyo), farmers do two to three weeding operations within the first 6 months of cassava growth. In Benue State, more farmers (56.8%) use family than hired (41.9%) labor in weed control whereas more farmers in Ogun (61.2%), Oyo (77.5%), and Abia (51.9) State use hired labor. Although negligible, some communal labor is used in Benue State to control weeds in cassava.

Across the four States, farmers used either pre- or post-emergence herbicides or both types (Table 4). Most of the herbicides used were formulations containing glyphosate, paraquat, atrazine, and s-metolachlor + atrazine (Table 4). However, farmers (64.4%) in Benue State use more post-emergence herbicides to control weeds in cassava than farmers in Oyo (42.3%), Ogun (34.6%), and Abia (6.7%) States. The majority of farmers in Benue (82.9%) and Ogun (60%) States who apply post-emergence herbicides mostly use glyphosate in different formulations (Table 4). Odomenem and Otanwa (20) reported that in 10 communities in Ohimini, Benue State, 63.8% of farmers use glyphosate for weed control in cassava. In Benue State, farmers use glyphosate in land preparation and this may explain the large number of them applying post-emergence herbicides. A common practice in Benue State is for farmers to plant cassava stakes about 60 to 80 cm long on mounds with cassava shoots sprouting from the upper buds. This allows farmers to spray glyphosate freely and repeatedly on weeds under the canopy without damaging the cassava. Repeated application of glyphosate in a particular field in a growing season is not a good practice as this could lead to weed resistance. There are fears in this SGS zone (Benue State) that E. *heterophylla* may be developing resistance to glyphosate as several farmers have reported poor control, even with repeated applications. In Oyo State, most farmers used glyphosate (60%) and paraquat (25%) as a post-emergence herbicide in cassava. For pre-emergence herbicides, the majority of farmers in Oyo State (25%) used atrazine wettable powder and while farmers in Abia State (40%) used S-metolachlor + atrazine. Although farmers who use herbicides apply it 3 - 4 times during the growth cycle, the majority of respondents in Benue (55.8%), Oyo (47.8%), and Oyo (39.1%) States apply herbicides only once. In Abia State, the majority (80%) apply herbicides twice. The frequency of herbicide application depended on the vegetation and type of herbicide used. In all the areas studied, farmers (62-73%) make use of contract sprayers for herbicide application.

Table 4: Percentage distribution of respondents from four cassava growing States (Benue,Ogun, Oyo and Abia) in Nigeria according to the product names of herbicides used by farmers.

Herbicide	Active ingredient	Benue	Ogun	Oyo	Abia
Pre-emergence					
Atrazine[†]	atrazine	10.53	16	22.91	10
Afalon	Linuron 450 g/l	-	-	2.08	-

Primextra Gold	S – metolachlor 290 g/l + atrazine 370 g/l	-	4	-	40
Post-emergence					
Glyphosate‡	glyphosate	39.48	44	45.83	40
Paraquat§	paraquat	40.79	28	27.08	10
2, 4-D	2, 4-D	-	2	-	-
Tackle	Chlorsulfuron 750 g/kg	-	2	-	-
UpRoot 240 EC	Clethodim 240 g/l	2.63	-	2.08	
Unknown					
Eapraw	Unknown	-	2	-	-
Kill-weed	Unknown	-	2	-	-

†Atrazine [Different formulations: Atrazine 42.2% WP, Atrazine 50% WP, Atrazine 80% WP]

‡ Glyphosate [Different formulations: Fitscosate, Roundup, Glycel, ClearWeed, Vinash, Delsate, Sarosate, ForceUp, Touchdown forte]

§ Paraquat [Different formulation: Weedoff, Gramozone, ParaForce, WeedCrusher, Slahser]

Conclusions

This study showed that agroecological zone is an important factor to be considered in the richness, abundance, and diversity of weed species. Although many species identified in this study were ubiquitous in occurrence, their richness and diversity varied across agroecological zones. This was clearly illustrated by DCA and CCA. The importance of soil pH, siltiness, Organic Carbon, Ca, K, mechanical cultivation (i.e., tillage), and weed management methods in clustering farms and weed distribution within and across agroecological zones was illustrated by CCA.

Surveys of fields and farmers identified *A. conyzoides*, *A. africana*, *C. rotundus*, *C. odorata,* and *P. maximum* as the five most important weeds in the HF zone. In the DS zone, *T. procumbens*, *I. cylindrica*, *C. odorata*, *C. diffusa,* and *E. heterophylla* were identified by farmers and field evaluation as the five most important weeds. In the SGS zone, the most five important weeds were *T. procumbens*, *E. heterophylla*, *I. cylindrica*, *Rottboellia cochinchinensis,* and *C. benghalensis*. The study showed that farmers' management of these weeds varied across ecological zones, suggesting that weed management strategies in cassava should be focused on agroecological zones. In the HF zone, hoe-weeding (51.2%) and slashing (43.0%) with machetes were the predominant methods of control. Herbicide use was low (5%). In contrast, herbicide use was high in the SGS zone and medium to high in the DS zone (Ogun State= 26.3%, Oyo State = 42.2%). In the DS zone, atrazine (used pre-emergence), paraquat, and glyphosate (used post-emergence) were the most widely used herbicides; glyphosate use was high in the SGS zone. In both ecological zones, farmers applied paraquat and glyphosate in the crop several times in a growing season, especially in the SGS zone where farmers rarely use pre-emergence herbicides in cassava. The use of herbicides in these zones will continue to expand with rising scarcity and cost of labor.. It is therefore important that farmers in these zones are educated through trainings on the basic principles of herbicides use. This training should cover safety, calibration, and the appropriate use of herbicides. It is crucial for the effective and efficient weed management in cassava and avoidance of development of resistant weeds owing to inappropriate use of herbicides. Currently an intervention under a Bill & Melinda Gates foundation-funded project is ongoing in these zones where pesticide applicators referred to as 'Spray Service Providers' (SSPs) who, in most cases, are also farmers receive training on the best way to use pesticides and to render this service to farmers in their communities for a fee.

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