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Synthetic Herbicide Use Practices in Soybean Production in Agroecological Zones I and II of Togo: Diversity, Application Practices and Determinants

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A B S T R A C T

The increasing use of synthetic herbicides in soybean production raises concerns regarding agricultural productivity, human health, and the environment. This study aimed to characterize the herbicides used, their application practices, and the factors influencing their selection in agroecological zones I and II of Togo. A survey was conducted among 537 soybean producers across 15 prefectures. Data were collected on the herbicides used, active ingredients, application rates, application periods, supply channels, product selection criteria, and phytosanitary protection practices. Statistical analyses combined Chi-square and Mann–Whitney tests, Multiple Correspondence Analysis, and logistic regression. The results revealed a high diversity of herbicides, dominated by glyphosate (52%), followed by imazethapyr (22.7%), butachlor (8.2%), and nicosulfuron (7.3%). The agroecological zone significantly influenced herbicide selection ($p < 0.001$). Informal networks accounted for 64.99% of herbicide supplies. Product efficacy, cost, and advice from vendors were the main factors influencing product selection. These findings highlight the need to strengthen technical support for producers, promote good phytosanitary practices, and enhance the control of herbicide distribution.

Introduction

Soybean (*Glycine max* (L.) Merr.) is currently one of the most important crops worldwide. Its annual production exceeds 350 million tonnes, mainly produced by Brazil, the United States and Argentina (Asad *et al.,* 2020). This legume is a major source of plant protein and edible oil and is also widely used in animal feed, industry and biofuel production (Gaguan and Nagal, 2025). In West Africa, soybean cultivation is expanding rapidly, driven by agricultural development policies and investments in value chains. This trend is particularly evident in Nigeria, Ghana, Côte d'Ivoire and Togo (Araújo *et al.,* 2025), where soybean contributes to food security, diversification of farmers' incomes and development of processing industries. However, the intensification of soybean production has been accompanied by increasing reliance on synthetic herbicides to control weeds and improve yields. Active ingredients such as glyphosate, atrazine, paraquat and metolachlor are widely used because of their efficacy and their ability to reduce manual weeding requirements (Gaguan and Nagal, 2025). In sub-Saharan Africa, adoption of these herbicides is increasing rapidly in soybean and maize production systems. Nevertheless, their use raises concerns regarding applicator health risks, soil and water contamination, biodiversity loss and the development of herbicide-resistant weeds (Otieno, 2023). In response to these challenges, recent research recommends integrating herbicides into integrated weed management strategies combining agronomic, mechanical and biological practices in order to reduce dependence on chemical inputs while maintaining crop productivity (Kumari *et al.,* 2024) (Araújo *et al.,* 2025). At the same time, innovations in herbicide formulations seek to improve efficacy while limiting environmental impacts. Despite the expansion of soybean cultivation in West Africa, knowledge of the herbicides used, their application practices and the factors determining their adoption remains limited, particularly in Togo. This study therefore aimed to characterize the synthetic herbicides used by soybean producers in agroecological zones I and II of Togo, analyze their application practices and identify the main factors influencing their selection, in order to contribute to the development of sustainable weed-management strategies.

Materials and Methods

Study Area

The study was conducted in agroecological zones I and II of Togo, covering the Savanes and Kara regions and part of the Centrale region. These zones, located between 8°30′ and 9° N, have contrasting agroclimatic conditions (Dantsey-Barry *et al.,* 2007). Zone I corresponds to a northern plain with a Sudanian climate, characterized by a rainy season from June to October and a dry season from November to May. The vegetation is dominated by wooded savannas with Acacia spp., Terminalia spp., Vitellaria paradoxa and Parkia biglobosa (Atakpama *et al.,* 2021). Zone II is a mountainous area with a Sudano-Guinean climate, characterized by a rainy season from April to October and highly anthropized vegetation dominated by Isoberlinia spp. (Gnamkoulamba *et al.,* 2018) (Magamana *et al.,* 2025). Farming systems in both zones are mainly based on cereals, tubers and legumes in a context of agricultural intensification.

Field Survey

Survey Sites

The field survey was conducted from June 2024 to February 2025 in all 15 prefectures of agroecological zones I and II of Togo. Seven prefectures were surveyed in agroecological zone I: Tône, Cinkassé, Kpendjal Ouest, Kpendjal, Tandjoaré, Oti and Oti Sud. Eight prefectures were considered in zone II: Kéran, Doufelgou, Dankpen, Bassar, Mô, Assoli, Kozah and Binah. Overall, the study covered 15 prefectures and involved 357 soybean producers. Agroecological zones I and II were selected because of their strategic importance for soybean production in Togo. These two zones account for a substantial share of the cultivated area and national soybean production. They also have contrasting agroecological characteristics that may influence cropping practices, particularly herbicide use (Dantsey-Barry *et al.,* 2007). The Savanes and Centrale regions are among the main soybean-producing areas in Togo and include a large proportion of producers and cultivated land.

Data Collection Methods

Two types of questionnaires were used: group and individual questionnaires. To facilitate the interviews, the questionnaires were administered to producers in local languages with the assistance of an interpreter. Farmers, whether farm owners or employees, aged at least 18 years, directly involved in soybean production and willing to participate in the study were interviewed. To ensure the reliability of the information collected, only producers with effective knowledge of cropping practices and herbicide use on their farms were included. Survey sites and producers were identified in collaboration with ICAT technicians.

Trade names and the different characteristics of herbicides used by producers were recorded, together with their sources and application methods. A preliminary survey was conducted among randomly selected producers in each prefecture to determine the sample size used in this study. This preliminary survey also helped identify localities and estimate the proportion of people who knew and used synthetic chemical herbicides. The sample size per prefecture was calculated using the formula of (Dagnelie, 1998):

$$n = \frac{(U1\text{-}\alpha/2)^2 \times p\,(1-p)}{d^2}$$

Where n is the sample size to be considered in each prefecture, p is the proportion of people who know and use chemical herbicides, U1-α/2 is the value of the standard normal variate for a risk α (α = 0.05; U1-α/2 = 1.96), and d is the expected margin of error for any parameter to be estimated, set at 5%.

Database Used

The database of plant-protection products authorized in Togo, updated in August 2025 by the Ministry of Agriculture, Village Hydraulics and Rural Development through the Directorate of Agricultural Production, served as the reference tool. It provides detailed information on products available on the market, including trade name, active ingredient, concentration, formulation, recommended application rate and pre-harvest interval (PHI). This database provided a relevant guide for identifying herbicides available to producers and potentially used in the agroecological zones studied.

Data Processing and Statistical Analysis

Data collected from soybean producers were coded, checked and entered into Microsoft Excel before statistical analysis using R version 4.5.2 (R Core Team, 2025) and IBM SPSS Statistics.

First, descriptive statistics were used to characterize the surveyed producers and establish an inventory of synthetic chemical herbicides used in soybean production. Qualitative variables were summarized as frequencies and percentages, whereas quantitative variables were described using means and standard errors. Associations between producers' sociodemographic characteristics and the types of herbicides used were assessed using the Chi-square test. The strength of observed associations was evaluated using Cramer's V coefficient. Normality of the distribution of applied herbicide rates was assessed using the Shapiro–Wilk test. Because the data were not normally distributed, application rates were compared between agroecological zones using the non-parametric Mann–Whitney–Wilcoxon test. To explore relationships among herbicide-use practices, Multiple Correspondence Analysis (MCA) was performed on qualitative variables related to phytosanitary practices, including herbicide type, application period, product source, personal protective equipment (PPE) used and herbicide selection criteria. This analysis identified the main dependency structures among variables and highlighted herbicide-use profiles within farms.

Factors associated with the source of herbicides used (formal or informal channel) were identified using a binary logistic regression model. Explanatory variables included agroecological zone, gender, age, education level, herbicide type, application period, personal protective equipment and product selection criteria. Model coefficients were expressed as Odds Ratios (OR) with 95% confidence intervals. Robust standard errors were used to improve the robustness of the estimates. Statistical significance was assessed at the 5% level.

Results and Discussion

Diversity, Types and Active Ingredients of Herbicides Used

Analysis of Table 1 shows that most surveyed producers were located in agroecological zone II, with 308 individuals (57.36%), compared with 229 (42.64%) in zone I. Men predominated in the sample, with 411 producers (76.54%), whereas women accounted for 126 individuals (23.46%). The 31–40-year age group was the most represented (201; 37.43%), followed by 18–30 years (166; 30.91%) and 41–50 years (141; 26.26%), while producers older than 50 years were a minority (29; 5.40%). Regarding education, producers with no formal education were the most numerous (220; 40.97%), followed by those with primary (149; 27.75%) and secondary education (137; 25.51%), whereas university-educated producers were poorly represented (31; 5.77%). Analysis of the association between producer characteristics and the types of herbicides used shows that only the agroecological zone was significantly associated with herbicide type ($\chi^2 = 13.68$; $p < 0.001$), although the strength of this relationship was weak (Cramer's V = 0.16). In contrast, no significant association was observed with gender ($\chi^2 = 0.22$; $p > 0.05$; V = 0.02), age ($\chi^2 = 2.20$; $p > 0.05$; V = 0.06) or education level ($\chi^2 = 0.48$; $p > 0.05$; V = 0.08). These results indicate that herbicide type varies more according to agroecological context than according to producers' sociodemographic characteristics.

The inventory revealed a wide diversity of herbicide trade names used in the two agroecological zones. Four main trade names stood out: Faaba-soja (17.1%), Barizaa (13.8%), Force-up (13.2%) and King-force (7.6%). Together, these four products accounted for 51.7% of citations, while the remaining products comprised 56 secondary or less frequently used trade names on the local market (Figure 1).

Analysis of active ingredients (Figure 2) showed a clear predominance of glyphosate (52%), followed by imazethapyr (22.7%), butachlor (8.2%) and nicosulfuron (7.3%). Together, these four active ingredients accounted for 90.2% of producers' choices. Other substances recorded, including paraquat chloride and atrazine, each had use frequencies below 4%.

The distribution of herbicides by type revealed differences between the two agroecological zones (Figure 3). In zone I, selective herbicides predominated, accounting for 51.9% of uses compared with 35.6% for non-selective herbicides. Conversely, in zone II, non-selective herbicides predominated at 64.4%, compared with 48.1% for selective herbicides. This distribution confirms differentiation in weed-management practices between the two agroecological zones.

Finally, statistical analysis of herbicide application rates showed that their distribution significantly deviated from normality according to the Shapiro–Wilk test ($W = 0.845$; $p < 0.001$). This non-normality justified the use of non-parametric statistical tests to compare herbicide application rates between agroecological zones.

Spatial Distribution and Herbicide Application Practices

The spatial distribution of herbicides revealed marked differences between the two agroecological zones. The heat map of trade names (Figure 4) shows that in zone I, producers' choices were mainly concentrated on Faaba-soja and Barizaa, which had the highest use intensities. In contrast, zone II was characterized by high use of Force-up, together with several secondary trade names, particularly King-force and Sarosate. This distribution reflects regional differences in preferences and local supply channels.

A similar trend was observed for active ingredients (Figure 5). In zone I, producers mainly favored imazethapyr, with moderate use of glyphosate, reflecting a greater orientation toward selective herbicides. In contrast, zone II was characterized by greater use of glyphosate. Other active ingredients, particularly butachlor and nicosulfuron, showed lower levels of use in both zones.

Comparison of application rates between agroecological zones using the Mann–Whitney (Wilcoxon) test revealed a statistically significant difference ($W = 25760$; $p < 0.001$). However, this difference did not appear to be related to a large difference between medians, which remained broadly similar, but rather to differences in the distribution of values. Zone I showed greater dispersion of application rates and high extreme values, indicating greater heterogeneity in application practices and potential overdosing. In contrast, zone II showed a more homogeneous distribution, with lower variability and range (Figure 6).

Regarding application periods, the "Pre-sowing and pre-emergence" strategy was the most frequent, adopted by 52.89% of producers (Figure 7). It was followed by the "Pre-emergence and post-emergence" combination, practiced by 25.51% of respondents. Applications exclusively at pre-emergence (11.73%) or post-emergence (9.87%) were less frequent. These results show a predominance of strategies combining several intervention periods in soybean weed management. However, the distribution of application periods varied significantly according to agroecological zone ($\chi^2 = 58.89$; $df = 3$; $p < 0.001$; Cramer's $V = 0.331$) (Figure 8). Although the "Pre-sowing and pre-emergence" strategy remained dominant in both zones, zone I had a higher proportion of combined "Pre-emergence and post-emergence" treatments, whereas zone II had a higher proportion of exclusively post-emergence applications. A Cramer's V of 0.331 indicates a moderate association between agroecological zone and application period.

Supply Channels, Selection Criteria and Protective Practices

Analysis of supply channels showed a strong dependence of producers on informal networks, which accounted for 64.99% of supplies, compared with 35.01% for formal channels (Table 2). However, this predominance of the informal sector did not vary significantly according to agroecological zone ($\chi^2 = 0.73$; $df = 1$; $p > 0.05$). The low Cramer's V coefficient ($V = 0.041$) therefore confirms a relatively homogeneous structure of supply channels across the two zones.

Herbicide selection appeared to be mainly guided by technical, economic and social considerations (Table 3). Product efficacy was the leading selection criterion, cited by 29.42% of producers. It was followed by price, which was decisive for 22.72% of farmers, and advice from vendors (20.11%). Recommendations from fellow farmers (14.90%) and the availability of only one brand on the local market (12.85%) completed the main factors guiding product choice. These results show that herbicide selection is based simultaneously on perceived performance, economic accessibility, and the influence of market actors and producers' social environment.

Regarding protective practices, the results showed very low use of personal protective equipment (PPE) during herbicide preparation and application. The vast majority of producers (86.41%) reported using no PPE. Wearing boots alone was the most common protective practice among those using equipment, but was limited to 7.08% of producers. Equipment combinations, particularly Com-Boots-Mask (2.05%) and Com-Boots (1.68%), were also uncommon (Table 4). These results indicate very limited use of protective measures during herbicide handling.

Typology of Herbicide Use Practices

The results of Multiple Correspondence Analysis (MCA) and hierarchical classification (Figures 9 and 10) revealed three distinct groups of producer practices. Group G1 was mainly associated with zone II, non-selective herbicides, the "Pre-sowing and pre-emergence" application strategy, the "Efficacy" selection criterion and formal supply channels. This profile corresponds to producers whose practices are characterized by the use of non-selective herbicides, early application and reliance on formal supply channels.

Group G2 was associated with zone I, selective herbicides, informal supply channels, and the criteria "Price", "Vendor advice" and "Fellow farmer". This group reflects product-selection practices that are more strongly linked to economic constraints and the influence of actors in the local environment, particularly vendors and other producers.

Group G3 was mainly characterized by the "None" category for personal protective equipment. Categories corresponding to PPE combinations, particularly "Com-Boots-Mask" and "Boots-Mask-Com-Gloves", were far from the center of the graph, reflecting their low frequency of use. This structure therefore highlights the strong predominance of non-use of PPE among producers, while the use of more complete protective equipment remains marginal.

Overall, the MCA and hierarchical classification identified three profiles of phytosanitary practices, differentiated mainly by agroecological zone, herbicide type, supply channel, selection criteria, application periods and level of applicator protection.

Determinants of Phytosanitary Practices

Logistic regression analysis showed that education level, product selection criteria and type of protection were the only factors that significantly influenced soybean producers' practices. Producers with secondary (OR = 0.386; $p < 0.001$) and university education (OR = 0.255; $p < 0.001$) had a substantially lower risk of exposure or poor practice than producers with no formal education. From an agronomic perspective, producers motivated by product "Efficacy" (OR = 0.457; $p < 0.01$) tended to protect themselves or select inputs more appropriately. Use of "Boots" as PPE also showed a significant protective effect (OR = 0.381; $p < 0.01$). Conversely, variables such as gender, age, agroecological zone and price had no statistically significant influence ($p > 0.05$) on these behaviors (Table 5).

Figure.11 shows the distribution of probabilities predicted by the model for producers' use of the informal market. The histogram is strongly left-skewed, indicating that a large majority of observations are concentrated at high predicted probabilities, between 0.60 and 0.85. The main distribution peak occurs around a probability of 0.78. Conversely, low probabilities remain marginal, indicating the robustness and predictive ability of the model.

The study conducted among 537 producers across 15 prefectures showed that agroecological zone was the main factor associated with the type of herbicide used, unlike gender and education level. This influence of agroecological context is consistent with observations by (Tamru *et al.,* 2017), while variability in soils and climate may also guide the choice of agricultural inputs (Agegnehu, Srivastava and Bird, 2017).

The inventory revealed a high diversity of herbicides, with four trade names (Faaba-soja, Barizaa, Force-up and King-force) predominating and accounting for 51.7% of citations. This concentration may be explained by their availability, cost and perceived efficacy. Similar findings were reported by (Kpienbaareh *et al.,* 2022) and (Tamru *et al.,* 2017), who emphasized the importance of accessibility, price and experiences shared among producers in product selection. Nevertheless, the presence of 56 other trade names indicates diversification of supply, particularly through pesticide distribution networks (Mphande *et al.,* 2025). Concentrating use on a few products may, however, promote the development of herbicide-resistant weeds and increase environmental risks (Heap, 2014; Duke, 2020).

Glyphosate was the main active ingredient used (52%), followed by imazethapyr (22.7%), butachlor (8.2%) and nicosulfuron (7.3%). Together, these four molecules accounted for 90.2% of producers' choices. The predominance of glyphosate may be related to its broad spectrum of activity, efficacy and economic accessibility, particularly in a context of declining labor availability (Duke, 2020; Soltani and Shropshire, 2022; Otieno, 2023). The importance of imazethapyr also reflects the use of selective herbicides adapted to soybean.

However, the strong concentration of practices on a few active ingredients highlights the need to diversify modes of action in order to limit the selection of resistance (Heap, 2014; Kumari *et al.,* 2024).

The distribution of selective and non-selective herbicides differed between zones. Zone I was more strongly characterized by the use of selective herbicides, whereas non-selective herbicides predominated in zone II. This difference may be related to agroecological conditions, weed pressure, labor constraints and the technical practices adopted. In sub-Saharan Africa, the use of non-selective herbicides is particularly favored when manual weeding becomes difficult or costly (Tamru *et al.,* 2017; Kpienbaareh *et al.,* 2022; Otieno, 2023). Differences in climate, weed flora and soil characteristics may also contribute to these variations (Agegnehu *et al.,* 2017).

Overall, these results show that soybean weed-management practices in Togo are highly diverse but remain concentrated around a limited number of active ingredients. They highlight the importance of integrated weed-management strategies combining cultural practices, diversification of modes of action and rational herbicide use in order to maintain efficacy and reduce health and environmental risks.

Analysis of herbicide application practices revealed differences between the two agroecological zones in both application rates and intervention periods. Comparison of rates using the Mann–Whitney test showed a statistically significant difference between zones. However, this difference was more closely related to the distribution of values than to a marked difference between medians. Zone I showed greater dispersion and high extreme values, suggesting more heterogeneous application practices and potential overdosing, whereas zone II showed a more homogeneous distribution.

This variability may be related to differences in access to technical information, producer training or reliance on empirical estimates when preparing spray mixtures. In sub-Saharan Africa, actual application rates frequently differ from recommendations because of limited access to extension services, poor adherence to label instructions or lack of appropriate measuring equipment (Jallow *et al.,* 2017; Damalas, 2021). Underdosing may reduce treatment efficacy and promote resistance selection, whereas overdosing increases costs and environmental contamination risks (Heap, 2014; Duke, 2020). These observations highlight the importance of strengthening producer training and promoting compliance with authorized application rates.

Application periods were also significantly associated with agroecological zones (Cramer's V = 0.331). Although the "pre-sowing and pre-emergence" strategy was dominant in both zones, zone I was characterized by more frequent combined "pre-emergence and post-emergence" treatments, whereas zone II had more exclusively post-emergence applications. These differences may be related to weed dynamics, agroecological conditions and work-organization constraints. The choice of application timing depends on weed pressure, climatic conditions and management objectives (Soltani and Shropshire, 2022). It may also be influenced by labor availability, access to equipment and technical advice received by producers (Tamru *et al.,* 2017; Kpienbaareh *et al.,* 2022). However, repeated post-emergence treatments and reliance on the same modes of action may increase selection pressure and promote herbicide resistance in weeds (Heap, 2014). Improving application practices should therefore be based on better control of application rates and treatment timing, as well as diversification of weed-management strategies.

Figure.1 Diversity and predominance of herbicides used according to trade names

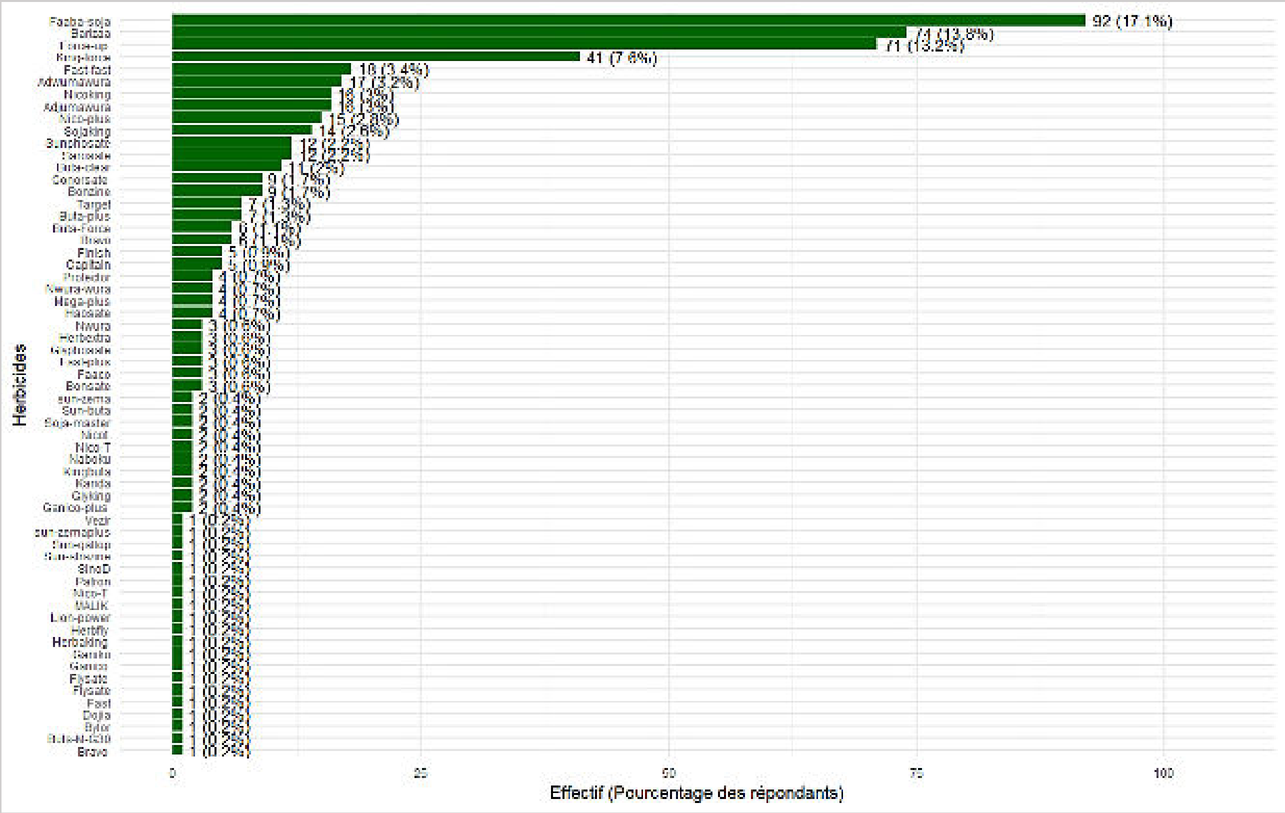


Figure.2 Matières actives des herbicides recensés

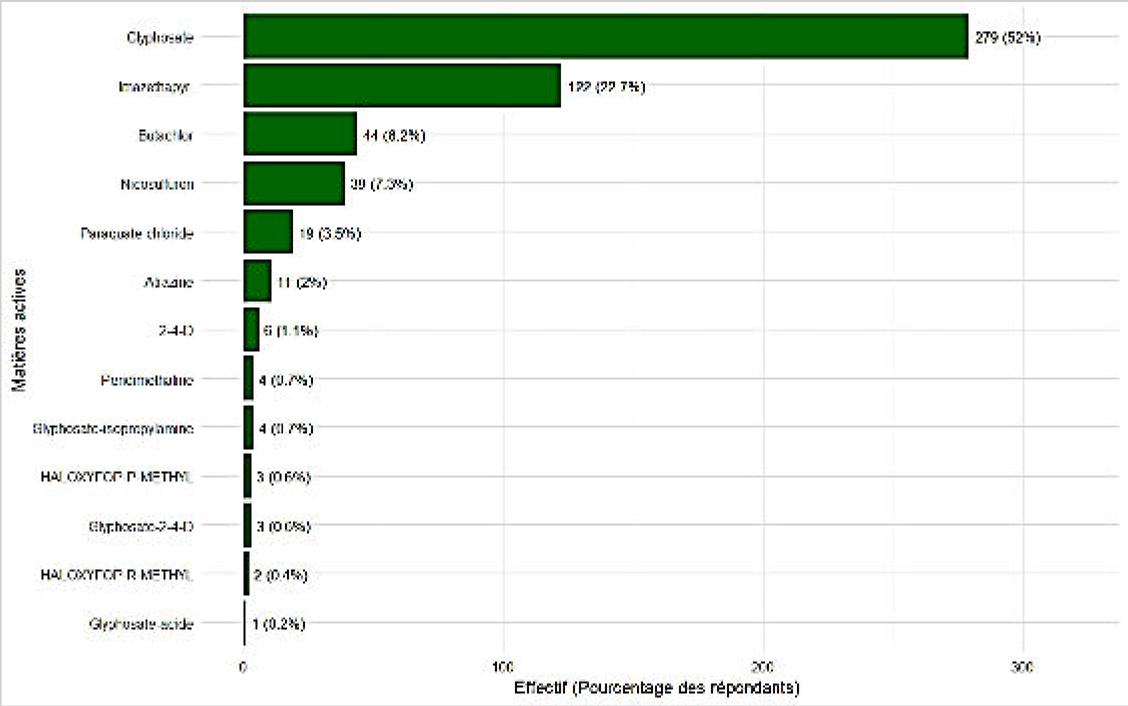


Figure.3 Proportional distribution of herbicide types used in soybean production according to agroecological zones I and II in Togo

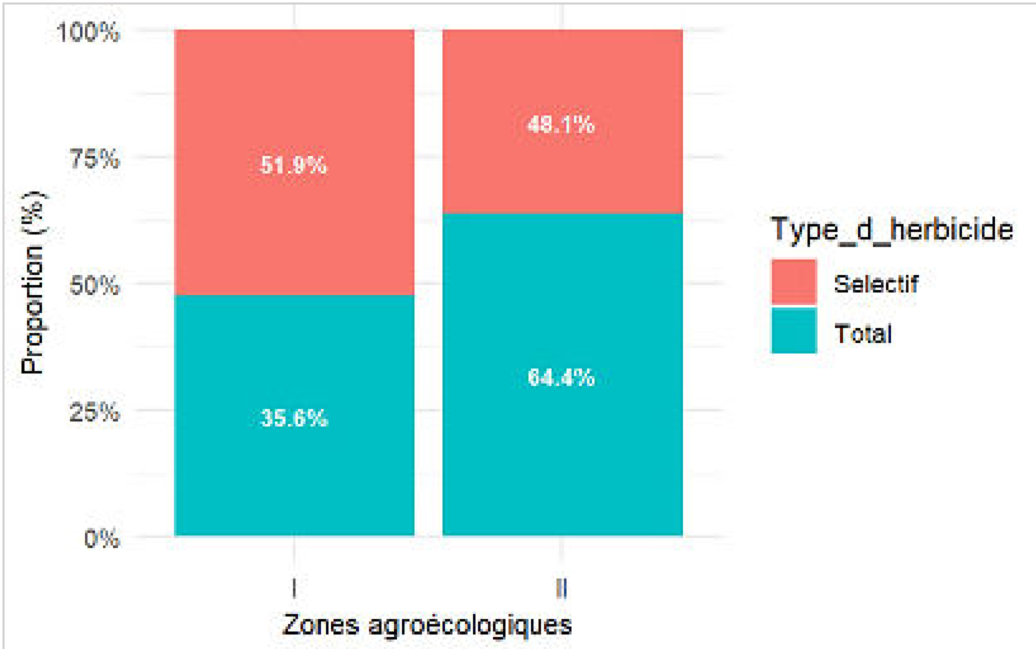


Figure.4 Heat map of the distribution and intensity of use of the different herbicide trade names according to agroecological zones I and II

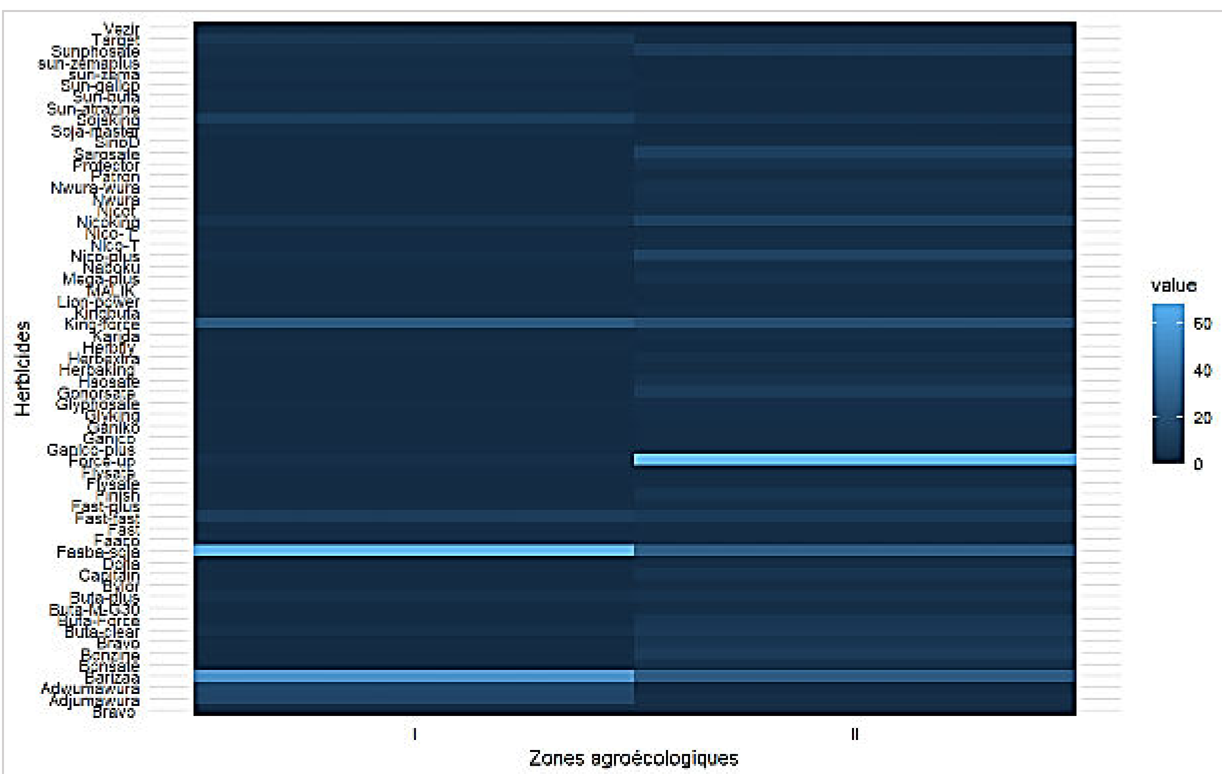


Figure.5 Heat map of the distribution and intensity of use of herbicide active ingredients according to agroecological zones I and II

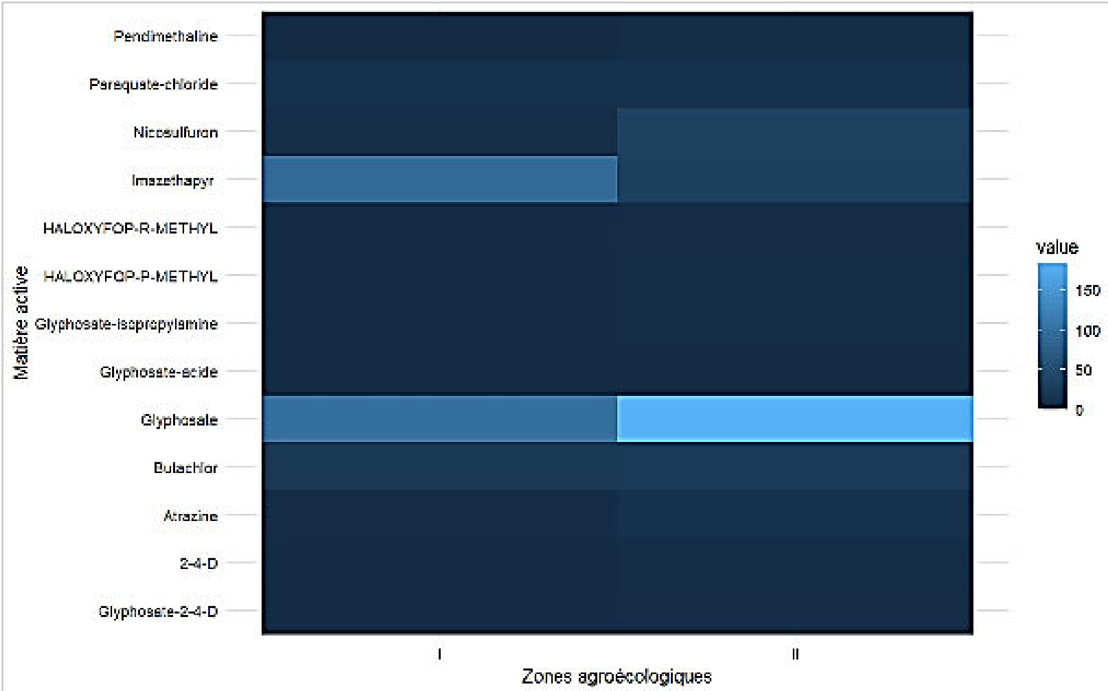
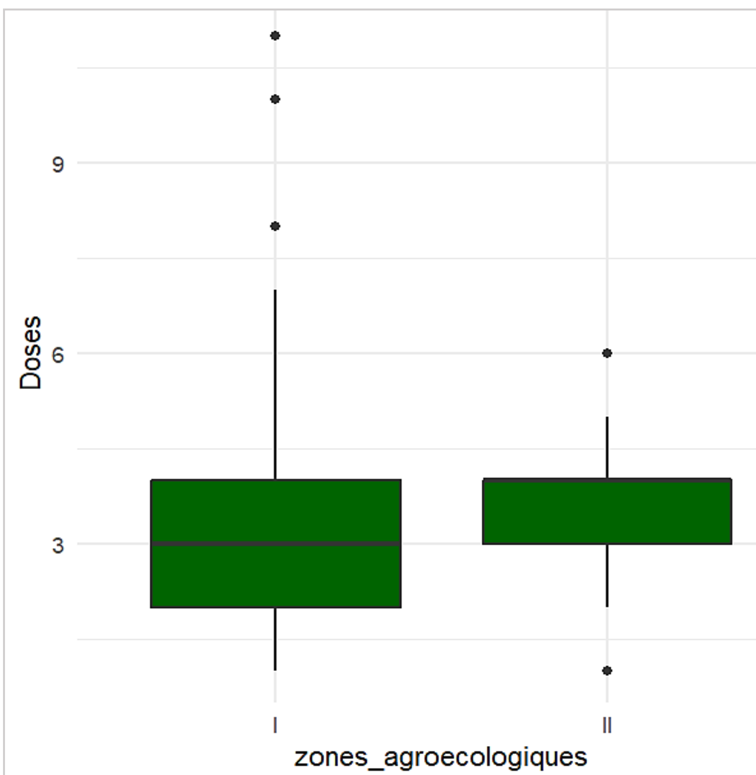


Figure.6 Comparison of application rates between agroecological zones



I: Zone I; II: Zone II

Figure.7 Distribution of soybean producers according to herbicide application periods in the study areas

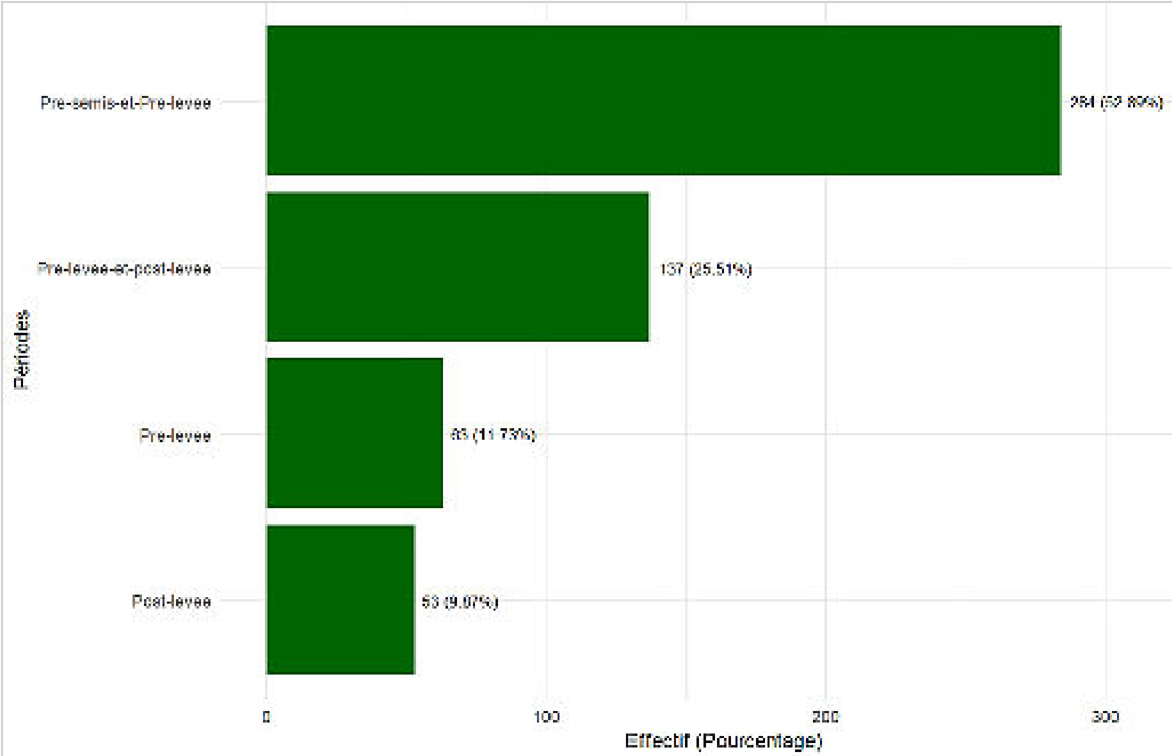


Figure.8 Distribution of herbicide application periods in soybean production according to agroecological zones I and II

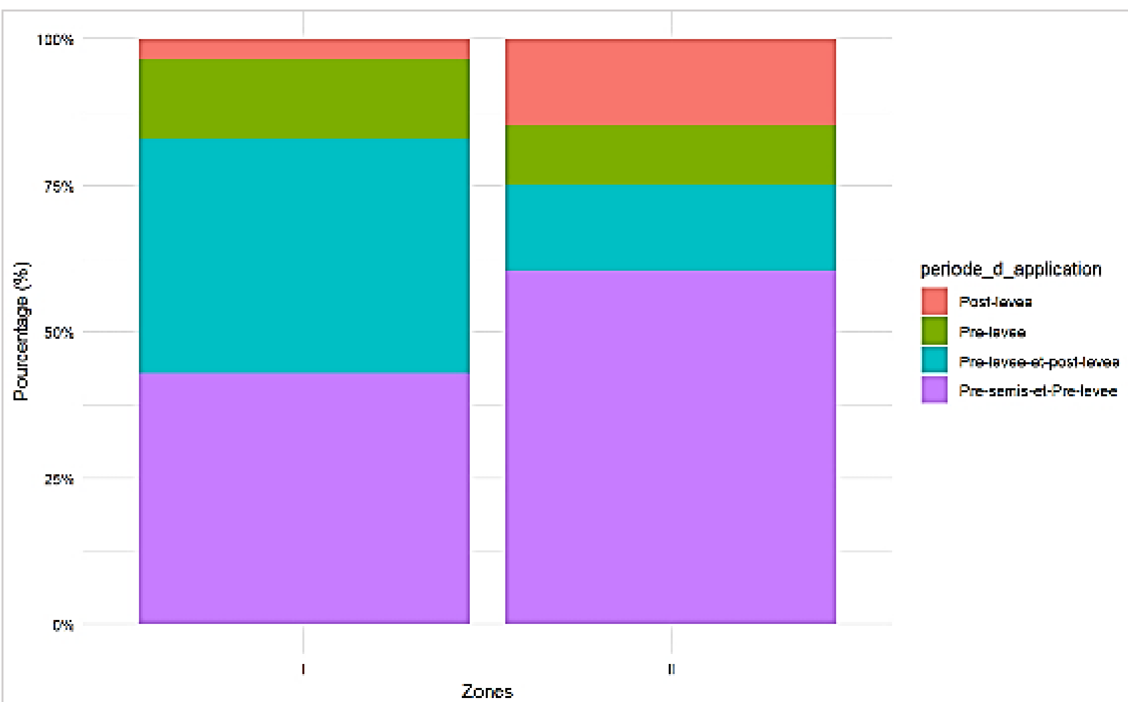


Figure.9 Multiple Correspondence Analysis (MCA) of determinants, herbicide types and protective practices according to agroecological zones

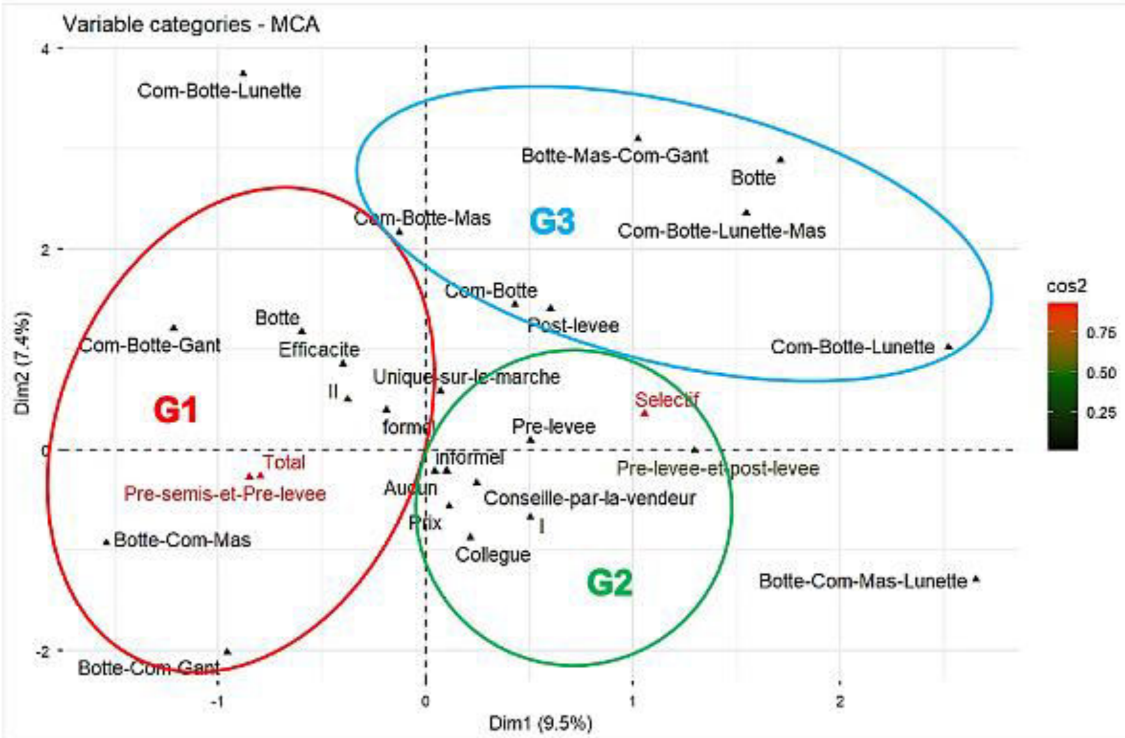


Figure.10 Hierarchical classification (cluster plot) of soybean producers according to the similarity of their practices

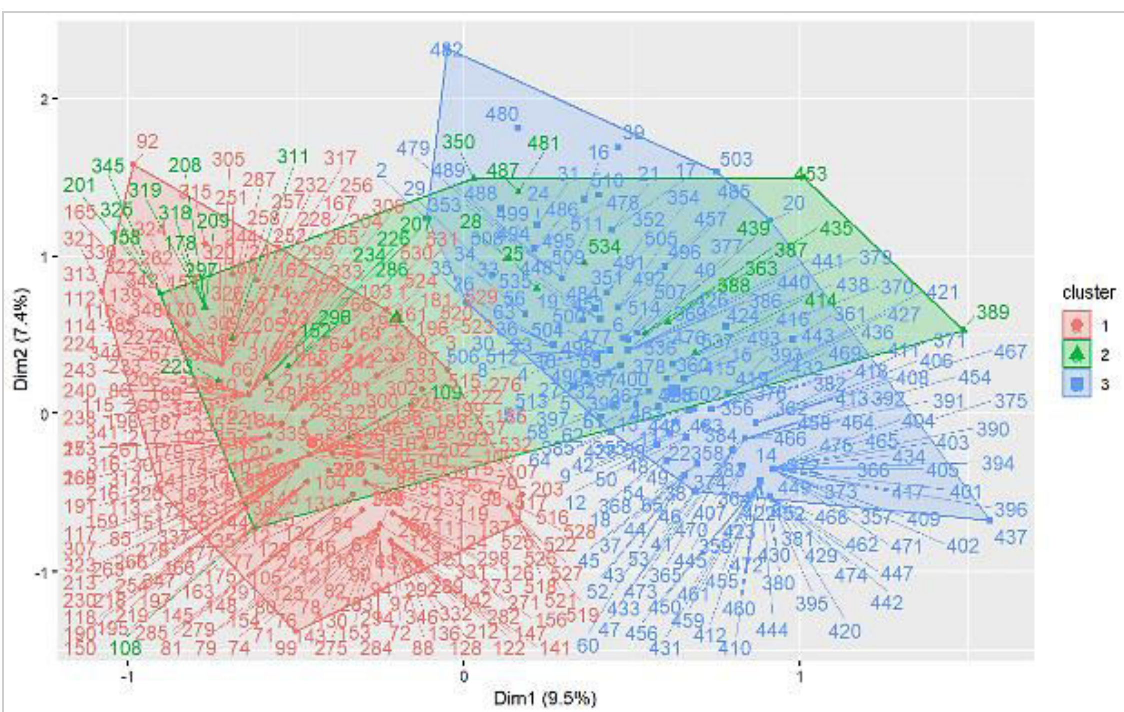


Figure.11 Distribution histogram of predicted probabilities of using informal supply channels among soybean producers

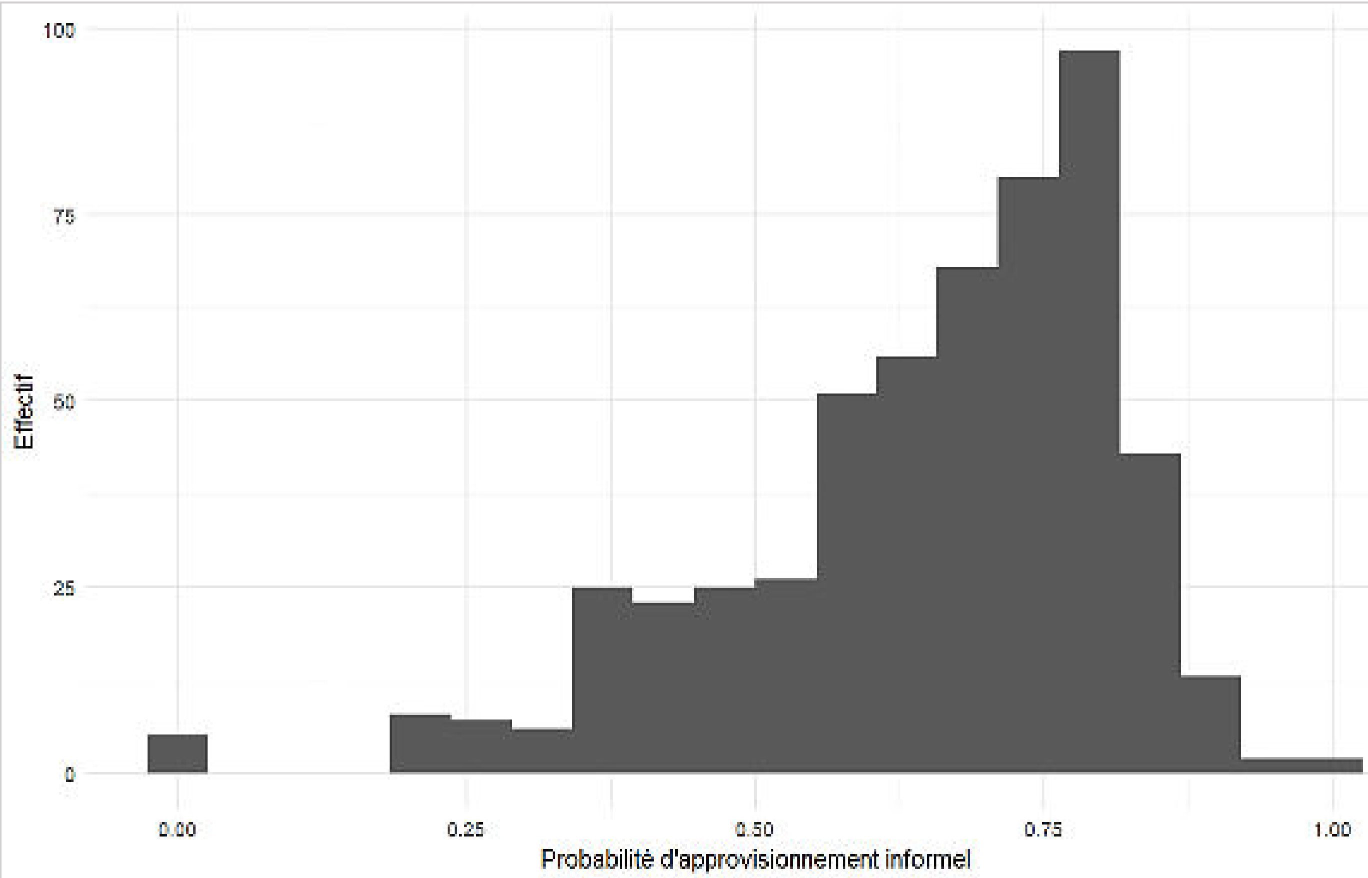


Table.1 Répartition des producteurs selon les caractéristiques socio-démographiques et analyse de leur association avec les types d'herbicides utilisés

Variables	Categories	Number (Proportion, %)	Association tests	
			Chi-square test (p-value)	Cramer's V
Agroecological zones	Zone I	229 (42,64)	χ^2=13,68***	V = 0,16
	Zone II	308 (57,36)		
Gender	Female	126 (23,46)	χ^2=0,22(ns)	V= 0,02
	Male	411 (76,54)		
Age	18-30ans	166 (30,91)	χ^2=2,20(ns)	V= 0,06
	31-40ans	201 (37,43)		
	41-50ans	141 (26,26)		
	> 50ans	29 (5,40)		
Education level	None	220 (40,97)	χ^2=0,48(ns)	V= 0,08
	Primary	149 (27,75)		
	Secondary	137 (25,51)		
	University	31 (5,77)		

***: p < 0,001; **: p < 0,01; *: p < 0,05; ns: p>0,05

Table.2 Répartition des producteurs de soja selon l'origine des herbicides

Product source	Number (n)	Percentage (%)
Formal	188	35,01
Informal	349	64,99

Table.3 Distribution of soybean producers according to determinants and selection criteria for synthetic herbicides

Product selection criterion	Number (n)	Percentage (%)
Fellow farmer	80	14,90
Vendor advice	108	20,11
Efficacy	158	29,42
Price	122	22,72
Only brand available on the market	69	12,85

Table.4 Distribution of soybean producers according to PPE used during herbicide application

PPE	Number (n)	Percentage (%)
None	464	86,41
Boots	38	7,08
Botte-Com-Gant	2	0,37
Botte-Com-Mas	1	0,19
Botte-Com-Mas-Lunette	1	0,19
Botte-Mas-Com-Gant	2	0,37
Com-Botte	9	1,68
Com-Botte-Gant	5	0,93
Com-Botte-Lunette	3	0,56
Com-Botte-Lunette-Mas	1	0,19
Com-Botte-Mas	11	2,05

Com: Combinaison de protection, Mas: Masque,

Table.5 Logistic regression analysis of sociodemographic and technical factors determining herbicide use practices among soybean producers

Variable	OR	IC95_inf	IC95_sup	p_value
(Intercept)	9,713	2,666	40,824	p<0,001
zones écologiques (II)	1,218	0,78	1,909	p>0,05
Genre (Masculin)	1,103	0,676	1,791	p>0,05
Age (18-30ans)	0,414	0,129	1,117	p>0,05
Age (31-40ans)	0,621	0,195	1,652	p>0,05
Age (41-50ans)	0,548	0,17	1,489	p>0,05
Niveau d'étude (Primaire)	0,844	0,51	1,4	p>0,05
Niveau d'étude (Secondaire)	0,386	0,23	0,641	p<0,001
Niveau d'étude (Universitaire)	0,255	0,111	0,577	p<0,001
Type d'herbicide (Total)	0,816	0,279	2,536	p>0,05
Période d'application (Pre-emergence)	0,614	0,248	1,494	p>0,05
Période d'application (Pre-emergence-and-post-emergence)	0,731	0,329	1,576	p>0,05
Période d'application (Pre-sowing-and-pre-emergence)	0,768	0,216	2,562	p>0,05
Choix du produit (Vendor advice)	1,142	0,569	2,28	p>0,05
Choix du produit (Efficacité)	0,457	0,235	0,867	p<0,01
Choix du produit (Prix)	0,814	0,42	1,555	p>0,05
Choix du produit (Unique-sur-le-marche)	0,577	0,267	1,237	p>0,05
Epi (Botte)	0,381	0,174	0,815	p<0,01
Epi (Botte-Com-Mas)	3855796,64	0		p>0,05
Epi (Botte-Com-Mas-Lunette)	0		2,249E+121	p>0,05
Epi (Botte-Mas-Com-Gant)	0,332	0,01	11,004	p>0,05
Epi (Com-Botte)	2,084	0,444	15,118	p>0,05
Epi (Com-Botte-Gant)	0,592	0,065	4,199	p>0,05
Epi (Com-Botte-Lunette)	0		1,924E+61	p>0,05
Epi (Com-Botte-Lunette-Mas)	2414434,56	0		p>0,05
Epi (Com-Botte-Lunette)	0		8,897E+121	p>0,05
Epi (Com-Botte-Mas)	1,027	0,279	4,287	p>0,05

OR: Odds ratio, IC: Interval de Confiance

Analysis of supply networks showed a strong dependence of soybean producers on informal channels, which accounted for 64.99% of supplies compared with 35.01% for formal channels. This predominance did not differ significantly between the two agroecological zones ($\chi^2 = 0.73$; $p > 0.05$; Cramer's V = 0.041), suggesting that it represents a structural constraint common to producers regardless of agroecological context. This situation is frequently reported in sub-Saharan Africa, where producers favor unlicensed retailers, local markets and intermediaries because of their proximity, immediate product availability, the possibility of purchasing small quantities or on credit, and sometimes more attractive prices (Otieno, 2023; Mphande *et al.,* 2025). However, reliance on informal channels may facilitate the circulation of unauthorized, counterfeit or inadequately labeled products, thereby increasing risks of dosing errors, poisoning and environmental contamination (Damalas & Koutroubas, 2016). Strengthening authorized channels and distribution controls is therefore necessary to improve supply safety and promote responsible herbicide use.

Herbicide selection was mainly based on technical and economic considerations. Product efficacy was the leading decision criterion (29.42%), followed by price

(22.72%) and vendor advice (20.11%). Recommendations from fellow farmers (14.90%) and the availability of only one brand on the local market (12.85%) also played a role. The predominance of efficacy reflects producers' search for solutions capable of providing satisfactory weed control, as weeds are a major constraint in soybean production. Similar trends have been observed in several African contexts, where the immediate efficacy of pesticides is often prioritized over health and environmental considerations (Damalas, 2021; Otieno, 2023). The importance of price reflects the economic constraints of family farms and the search for affordable inputs (Tamru *et al.,* 2017; Kpienbaareh *et al.,* 2022).

The importance of vendor advice highlights their central role in guiding phytosanitary practices, particularly where extension services are insufficient (Mphande *et al.,* 2025). However, inadequate training of some vendors may lead to recommendations that do not comply with good pesticide-use practices (Damalas and Koutroubas, 2016). Recommendations from fellow farmers also demonstrate the importance of local social networks in disseminating agricultural practices. Finally, limited availability of certain brands may restrict producers' ability to choose products best suited to their needs. These results therefore highlight the need to strengthen technical support for producers and distributors, improve access to authorized products and diversify supply sources in order to promote safer and more rational herbicide use.

Multivariate analysis of herbicide-use practices revealed contrasting producer profiles, reflecting the diversity of weed-management strategies and behaviors toward phytosanitary risks. One profile comprised producers primarily seeking effective weed control from the earliest crop stages. The use of non-selective herbicides acquired through formal channels reflects a technical-performance strategy aimed at securing soybean establishment. This strategy is consistent with Soltani & Shropshire (2022), who reported that early herbicide applications are an important means of limiting weed competition and preserving yield potential. However, prioritizing efficacy may sometimes place personal protection measures and environmental considerations in the background (Damalas, 2021). Zone I, associated with the variables "Price", "Vendor advice" and "Fellow farmer", together with the "informal" market and "selective" herbicides, appears to characterize farms that are more sensitive to economic constraints and strongly influenced by their immediate social environment. Purchasing decisions are mainly based on product affordability and advice from local networks. Similar findings were reported by Mphande *et al.,* (2025), who showed that input vendors and exchanges among producers are major sources of information and guidance for phytosanitary choices in African farming systems. Dependence on informal channels may nevertheless increase the risk of purchasing unsuitable or poorly regulated products (Otieno, 2023). Health-protection behavior was dominated by the "None" category adopted by most producers, whereas complete PPE combinations such as "Com-Boots-Mask" or "Boots-Mask-Com-Gloves" appeared isolated, confirming their very marginal use. This situation indicates a low perception of the chemical risks associated with herbicide use. Numerous studies in developing countries have shown that inadequate PPE use results from limited awareness, high equipment costs, poor availability and discomfort under hot climatic conditions (Damalas & Koutroubas, 2016; Jallow *et al.,* 2017). Repeated pesticide exposure without adequate protection nevertheless increases the risk of acute poisoning and chronic health effects among applicators.

Identifying factors associated with phytosanitary practices helps clarify the determinants of producer behavior and guide interventions aimed at promoting safer herbicide use. Logistic regression analysis showed that education level, product selection criteria and type of protection used were the only factors significantly influencing soybean producers' phytosanitary practices. Producers with secondary and university education had a significantly lower risk of exposure or poor practices than producers with no formal education. Agronomically, producers whose herbicide selection was motivated by product efficacy appeared to adopt more appropriate practices in selecting and using inputs. Finally, wearing "Boots" as personal protective equipment also had a significant protective effect. In contrast, variables such as gender, age, agroecological zone and product price showed no statistically significant influence on observed behaviors. These results highlight the determining role of education in adopting good phytosanitary practices. Educated producers are generally better able to understand product labels, interpret technical recommendations and perceive pesticide-exposure risks. Similar observations were reported by Damalas & Koutroubas (2016), who showed that education is a major factor in improving pesticide-handling behavior. Likewise, Jallow *et al.,* (2017) emphasized that farmers with higher education levels have better knowledge of safety measures and use personal protective equipment more frequently.

The association between product efficacy and reduced risk suggests that producers focused on technical performance pay greater attention to product selection and compliance with application practices. This observation is consistent with Damalas (2021), according to whom a better perception of the agronomic benefits of pesticides is often accompanied by more rational input use. The protective effect observed for wearing boots confirms the importance of personal protective equipment in reducing pesticide exposure. Even when used only partially, some PPE helps limit direct contact with plant-protection products and reduce health risks (Damalas & Koutroubas, 2016). Nevertheless, the limited use of complete protective equipment observed in this study remains a concern and highlights the need to strengthen awareness activities and improve producers' access to PPE. Finally, the lack of significant association of gender, age, agroecological zone and price with phytosanitary practices suggests that these behaviors depend more on acquired knowledge and risk perception than on producers' sociodemographic characteristics. This conclusion supports the findings of Damalas (2021), who indicated that skills and information play a greater role than individual characteristics in the adoption of safe practices.

In conclusion, this study characterized synthetic chemical herbicide-use practices in soybean production in agroecological zones I and II of Togo. The results revealed a wide diversity of commercial products, although use was strongly concentrated around a few dominant formulations. Faaba-soja (17.1%), Barizaa (13.8%), Force-up (13.2%) and King-force (7.6%) together accounted for 51.7% of the herbicides cited by producers. Analysis of active ingredients showed a clear predominance of glyphosate, used by 52% of respondents, followed by imazethapyr (22.7%), butachlor (8.2%) and nicosulfuron (7.3%), together representing 90.2% of reported choices.

Herbicide-use practices differed according to agroecological context. Zone I was characterized by greater use of selective herbicides (51.9%), whereas zone II favored non-selective herbicides (64.4%). In addition, nearly two-thirds of producers (64.99%) obtained herbicides through informal channels. Product selection was mainly based on efficacy (29.42%), affordability (22.72%) and vendor advice (20.11%). Multivariate analysis identified three distinct producer profiles, reflecting diversity in phytosanitary behavior. Logistic regression further showed that education level, herbicide selection criteria and the use of protective equipment significantly influenced producer practices.

These results highlight the need to strengthen extension and training programs on proper herbicide use, improve control of distribution channels and promote the use of personal protective equipment. Integrating weed-management strategies is also essential to reduce the health and environmental risks associated with pesticide use. Finally, further research on herbicide residues in soils and agricultural products, as well as their long-term effects on agroecosystems, will help support the development of public policies promoting safer and more sustainable soybean production in Togo.

Author Contributions

DEMAKOU Meyéme: Investigation, formal analysis, writing—original draft. TCHABI Atti: Validation, methodology, writing—reviewing. FAMAH SOURASSOU Nazer:—Formal analysis, writing—review and editing.

Data Availability

The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethical Approval Not applicable.

Consent to Participate Not applicable.

Consent to Publish Not applicable.

Conflict of Interest The authors declare no competing interests.

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