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Research Article

Keywords: farm typology, farming system, market gardening, pesticide management, Burkina Faso, sustainable development goals

Posted Date: November 11th, 2026

DOI: https://doi.org/10.21203/rs.3.rs-11210466/v1

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Additional Declarations: No competing interests reported.

Cropping and phytosanitary management led-farmer socio-demographic profile in market-garden systems in the Sudano-Sahelian zone of Burkina Faso

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Abstract

Market-gardening systems in Burkina Faso include farmers with contrasting access to land, labour and production resources, but the extent to which this heterogeneity is associated with differences in cropping and pesticide management remains poorly understood. This study aims to contribute to the development of strategies for reducing reliance on synthetic pesticides in market-gardening systems in the tropical Sudano-Sahelian zone of West Africa, in line with Sustainable Development Goals (SDG) 2, 3, 5 and 12. A survey of 300 market gardeners across urban, peri-urban and rural production environments in the Sudano-Sahelian zone of Burkina Faso was conducted. Multiple correspondence analysis followed by hierarchical clustering identified three farm types. Small rural farms managed predominantly by women and characterised by limited land and labour resources (G1; 33.7%); established farms managed mainly by men and relying largely on inherited land (G2; 52.7%); and younger, more highly educated peri-urban farmers cultivating rented land with larger labour (G3; 13.7%). Practice differed significantly among farm types. Micro-irrigation was concentrated in G3 (70.7%) but was rare in G1 (3.0%) and G2 (5.1%), whereas surface irrigation was used by more than 91% of farmers in G1 and G2. Synthetic pesticide use was general (95.6-98.0%), although pesticide mixing was more frequent in G2 (72.2%). Twenty-five pesticide chemical classes were recorded, with pyrethroids and avermectins predominating across groups. The crops receiving the most pesticide treatments differed significantly among farm types (Chi-2 = 173.52, $p < 0.001$). Tomato predominated in G1 (44.0%), cabbage in G2 (61.4%) and chilli pepper in G3 (39.0%). These findings show that farmer profiles capture important differences in cropping and pesticide management, while reliance on synthetic pesticides remains widespread across farm types. Extension strategies should therefore combine profile-specific agronomic advice with broader integrated pest management and pesticide-risk reduction measures. Such targeting can contribute to safer food production (SDG 2, 3, 12) and to narrowing gender gaps in access to resources (SDG 5).

Keywords: farm typology; farming system; market gardening; pesticide management; Burkina Faso; sustainable development goals

1. Introduction

Urban growth is reshaping food production across the global south, while vegetable production is becoming increasingly important for both nutrition and smallholder incomes [1,2]. This intensification, however, is often accompanied by greater pesticide use. Across countries, pesticide use per hectare rises more than proportionally with crop output per hectare, while regulation of hazardous pesticides tends to be weaker in lower-income countries [3]. These trends raise concerns for occupational exposure, food safety and environmental health [4].

These issues are particularly relevant in the tropical Sudano-Sahelian zone of West Africa, where rainfed production is largely confined to a short rainy season, and agriculture is increasingly exposed to climatic variability and warming [5]. Irrigated market gardening has therefore become an important source of income, employment and dietary diversity, while also contributing to livelihood diversification and the supply of rapidly growing cities [6–8]. Its recent expansion has been driven by urban demand, climatic uncertainty, land pressure and wider access to irrigation technologies [9,10], while providing opportunities for women and young farmers to enter commercial agriculture [11,12]. Yet opportunities are unevenly distributed. Indeed, access to land, water, labour and capital depends on both formal rights and social relations, and women remain disadvantaged in landownership in many African countries [13,14]. Market-gardening systems are therefore heterogeneous in their resource endowments, constraints and management strategies [15]. This heterogeneity is significant for the Sustainable Development Goals (SDGs), particularly concerning sustainable and productive food production systems (SDG 2) and the equal rights of women to economic resources and access to land (SDG 5).

Pesticide management illustrates the consequences of this heterogeneity. Pesticide imports into West Africa increased rapidly between 2005 and 2015, while fraudulent products and weak post-registration control remained widespread [16,17]. Pressure from invasive pests such as *Tuta absoluta* has further increased dependence on crop protection [18,19]. In Burkina Faso, less than 10% of market-garden farmers have received crop-protection training, and 90% purchased pesticides from local markets where product quality and regulatory compliance could not be assured [18]. Moreover, fewer than half of the recorded formulations were registered for vegetables, and products intended for cotton were also applied to vegetables consumed fresh [20].

Such practices increase risks to farmers, consumers and ecosystems [21–23]. Although training, safer handling, biopesticides, biological control and integrated pest management (IPM) have been promoted, adoption remains limited, partly because technical support is insufficient [24–26]. Reducing reliance on synthetic pesticides is crucial for decreasing illnesses and fatalities associated with hazardous chemicals and pollution (SDG 3) and for the environmentally sound management of chemicals (SDG 12).

A less examined issue is whether differences among farmers themselves help explain variation in management. Farmers differ in access to land, labour, capital, inputs and information, yet crop-protection interventions rarely account explicitly for this heterogeneity. Farm typologies provide a way to represent such differences and have been used to target interventions and inform agricultural policy [27–29]. By distinguishing farmers according to their resources, typologies can also help interventions reach those with the least access, in line with the commitment of the 2030 Agenda to leave no one behind [30]. Typologies of market-gardening and urban farming systems already exist in West Africa, including Burkina Faso [31–33]. However, some studies have included management variables in the construction of farm types, creating a risk that subsequent differences in management partly reflect the classification itself. When typologies are intended to explain management, they should therefore be based on characteristics that are independent of the practices being assessed [28,34,35].

The Sudano-Sahelian zone of Burkina Faso provides a relevant setting to address this gap. Indeed, previous typology studies have focused mainly on the Ouagadougou-Bobo-Dioulasso axis, whereas the eastern part of the country remains comparatively understudied [32,33,36]. Eastern production systems also differ in water access, input supply and exposure to insecurity, factors that may influence both farming and pesticide-management practices [36,37].

This study aims to contribute to the development of strategies for reducing reliance on synthetic pesticides in market-gardening systems in the tropical Sudano-Sahelian zone of West Africa by accounting for the heterogeneity of farmers and their management practices, thereby supporting progress towards SDG 2, 3, 5 and 12. Specifically, the study aims to (i) develop a farm typology based on farmers'

sociodemographic characteristics; (ii) assess variation in cropping practices among the resulting farm types; and (iii) characterise pesticide-management practices across farm types. We hypothesised that (H1) market-gardening farms can be grouped into a limited number of distinct types; (H2) farming practices differ among farm types; and (H3) phytosanitary management differs among farm types.

2. Materials and Methods

2.1. Study area

The survey was conducted in three regions Kadiogo, Oubri and Goulmou located in the Sudano-Sahelian zone of Burkina Faso (Fig. 1). Nine communes were selected owing to the importance of vegetable cultivation [32,38] and to capture the diversity of market gardening environments by including urban, peri-urban and rural production areas [20].

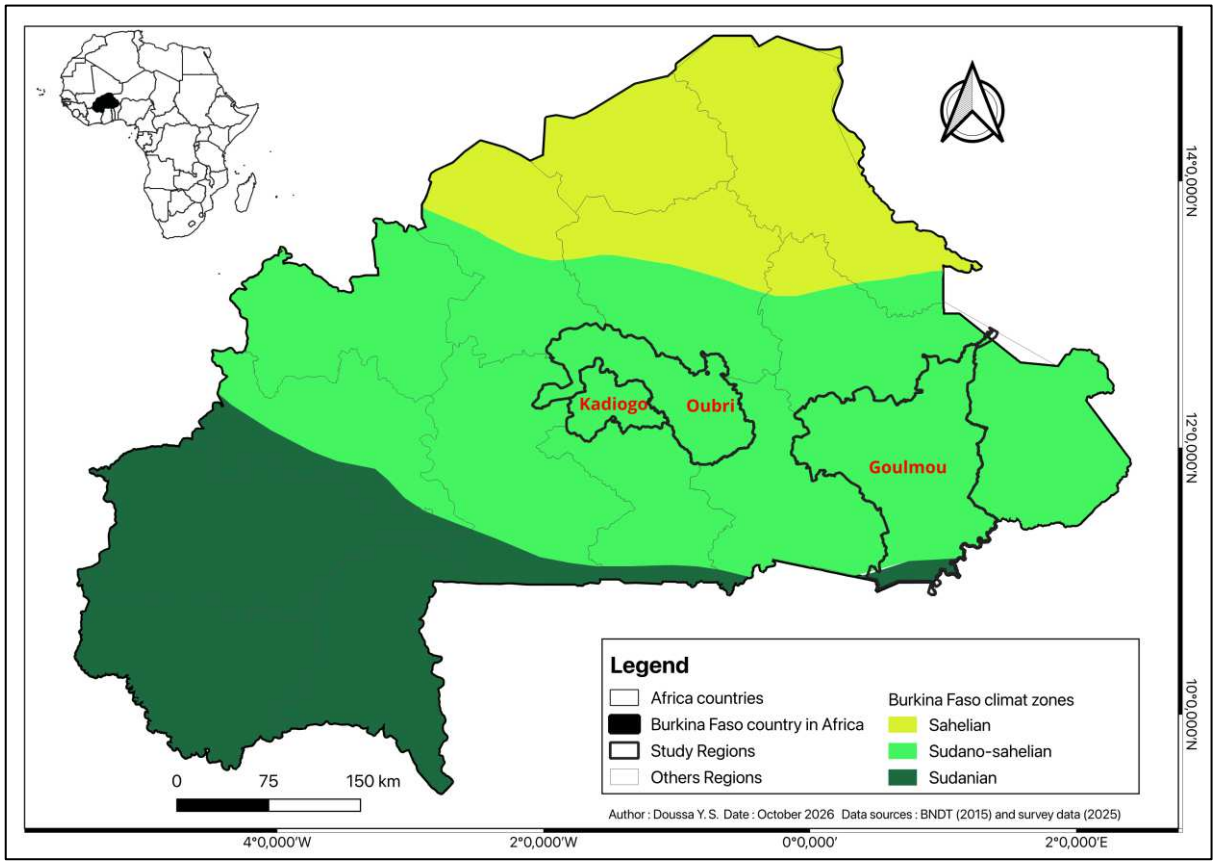


Fig. 1 Geographical location of the study zones

I.1. Sampling

Within each region, farms were selected by stratified sampling, stratified by production environments (urban, peri-urban and rural). A total of 300 farms were surveyed, distributed across 10 sites belonging to nine communes. Thirty (30) vegetables farmers were interviewed per site (Table I).

Table 1 Distribution of surveyed farms

Regions	Communes	Market gardening sites	Production environment	Sample size
Kadiogo	Ouagadougou	Boulmiougou	Urban	30
	Koubri	Minassma	Peri-urban	30
	Pabré	Pabré	Peri-urban	30
Oubri	Saaba	Saaba	Peri-urban	30
	Loumbila	Loumbila	Peri-urban	30
Goulmou	Fada N'Gourma	Taanjiama	Urban	30
	Diapangou	Licayenli	Peri-urban	30
	Tibga	Tibga	Rural	30
	Diabo	Zanré	Rural	30
		Kaoumé	Rural	30

2.2. Data collection

Data were collected through individual semi-structured interviews with the heads of 300 market gardening farms. The interview guide covered farmers' sociodemographic characteristics, farming practices, and phytosanitary management (Table II). For phytosanitary management, respondents reported the products used, the organisms targeted, and the crop receiving the most frequent pesticide treatments. Product labels were recorded when available to identify active substances, chemical families, and registered crop uses.

The questionnaire was programmed in KoboCollect v2025 and administered between February and May 2025. Informed consent was obtained from all respondents before each interview.

2.3. Data analysis

Farm types were identified using multiple correspondence analysis (MCA) followed by hierarchical clustering on principal components (HCPC). Clustering was performed on the MCA factor coordinates using Ward's minimum-variance method [28,39], thereby reducing dimensionality before grouping farms according to similarities in their characteristics. Only farmers' sociodemographic and farm structural characteristics were included as active variables in the classification (Table II). Farming and phytosanitary-management variables were excluded from the typology construction

and were subsequently analysed in relation to the resulting farm types. Commune, ethnicity, and production environment were included as supplementary variables in the MCA to assess their associations with the resulting farm types without contributing to the classification.

Associations between farm type and individual farming or phytosanitary management practices were assessed using Pearson's Chi-2 test of independence. Fisher's exact test was used when expected cell frequencies did not satisfy the assumptions of the Chi-2 test [40,41]. Modalities characterising each farm type were subsequently identified using the v-test, which compares the frequency of a modality within a group with its frequency in the overall sample [42,43]. Modalities with an absolute v-test value greater than 1.96 were considered significantly associated with a farm type. Positive values indicated over-representation within the group, whereas negative values indicated under-representation. Where multiple comparisons were performed, p-values were adjusted using the Benjamini-Hochberg procedure [44,45].

Phytosanitary products reported by farmers were standardised according to their active substances and classified by pesticide type and chemical family. Treatment targets were grouped into insect and mite pests, fungal pathogens, and weed categories. For each formulation, registered crop uses were identified from the product label and compared with the reported use of the product in market-garden vegetable production. Farmers were also asked to identify the crop receiving the most frequent phytosanitary treatments. The distribution of the most-treated crop was expressed as the percentage of valid respondents within each farm type and compared among groups using Pearson's Chi-2 test of independence. The diversity of crops reported as receiving the most frequent phytosanitary treatments was described separately for each farm type.

All statistical analyses were performed in R version 4.5 [46]. Multivariate analyses were conducted using the *FactoMineR* package [42,47], and graphical representations were produced using the *ggplot2* package. Statistical significance was assessed at the 5% level.

Table 2 Variables and modalities recorded in the survey

Variable categories	Variable	Modalities
Farmer profile (active variables)	Gender	Man; Woman
	Age	<25; [25–35[; [35–45]; >45
	Education level	No formal education; Primary; Secondary; Higher
	Farming experience	<10 yr; [10–20]; >20
	Farming knowledge	Self-taught; From other farmers
	Household size	<5; [5–10[; [10–15[; >15
	Land tenure	Rent; Inheritance; Purchase; Communal landholding; Loan
	Cultivated area (ha)	<0.25; [0.25–0.50[; [0.50–1[; >1
	Farm employees	1;]1–3]; >3
Location (supplementary variables)	Commune	Ouagadougou; Koubri; Pabré; Saaba; Loumbila; Fada N'Gourma; Diapangou; Tibga; Diabo
	Production environment	Urban; Peri-urban; Rural
	Ethnicity	Bissa; Ewe; Gourmantché; Kassena; Mossi; Yaana; Zoaga
Cropping practices (outcome)	Cropping season	Hot dry; Cold dry; Humid
	Water source	Borehole; Reservoir; Well
	Irrigation method	Micro-irrigation; Sprinkler; Surface
	Fertilisation	Manure; NPK; Urea
	Soil and crop management	Crop rotation; [complete]
Phytosanitary management (outcome)	Crop stage treated	Nursery; Vegetative growth; Flowering; Fruiting; Maturation
	Time of application	Morning; Midday; Evening; Unspecified
	Pest management	Synthetic pesticides used; Pesticides mixing

3. Results

3.1. Market-garden farm typology

The multiple correspondence analysis showed that the first two dimensions accounted for 22.0% of the total inertia, with 12.7% explained by Dimension 1 and 9.3% by Dimension 2 (Fig. 3). Dimension 1 was mainly associated with land access, farm size, gender and labour availability (Farm employees), whereas Dimension 2 was associated mainly with age and education, separating younger and more highly educated farmers from older farmers with little or no formal education (Fig. 3).

Hierarchical clustering on the MCA coordinates identified three farm types; G1 comprised 101 farms (33.7%), G2 158 farms (52.7%) and G3 41 farms (13.7%) (Fig. 4). Each of the nine active variables included at least one modality that significantly characterised one of the three groups (Fig. 5).

G1 was characterised mainly by woman farmers operating small farms, with cultivated areas below 0.25 ha, limited labour and frequent access to land through communal allocation or loans (Fig. 5). G2, the largest group, consisted predominantly of experienced male farmers cultivating inherited land, with intermediate farm sizes and one to three farm employees (Fig. 5). G3 was the smallest and most distinct group, characterised by younger and more highly educated farmers, rented land and farm employees exceeding three people (Fig. 5).

Although location-related variables were not used to construct the typology, the three groups differed in their distribution across production environments. Rural farms accounted for 59% of G1, whereas 88% of G3 farms were peri-urban and none were located in rural areas. G2 farms were distributed mainly across peri-urban and urban production environments (Fig. 6).

Overall, the typology distinguished three contrasting profiles: (i) woman farmers managing small rural farms with limited land and labour resources (G1); (ii) experienced male farmers managing medium-sized farms, mainly on inherited land and with intermediate labour availability (G2); and (iii) younger, predominantly peri-urban farmers cultivating rented land and relying on larger workforces (G3).

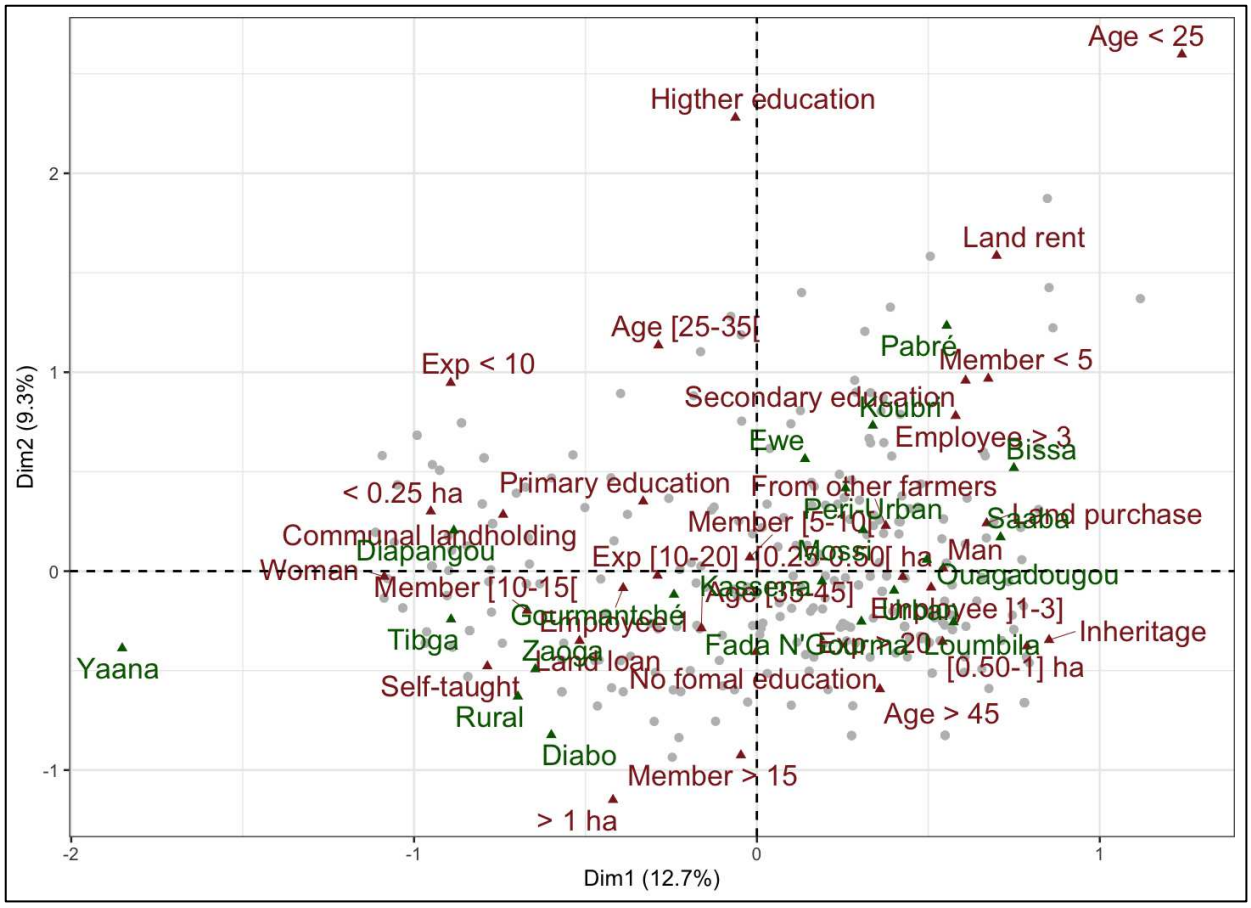
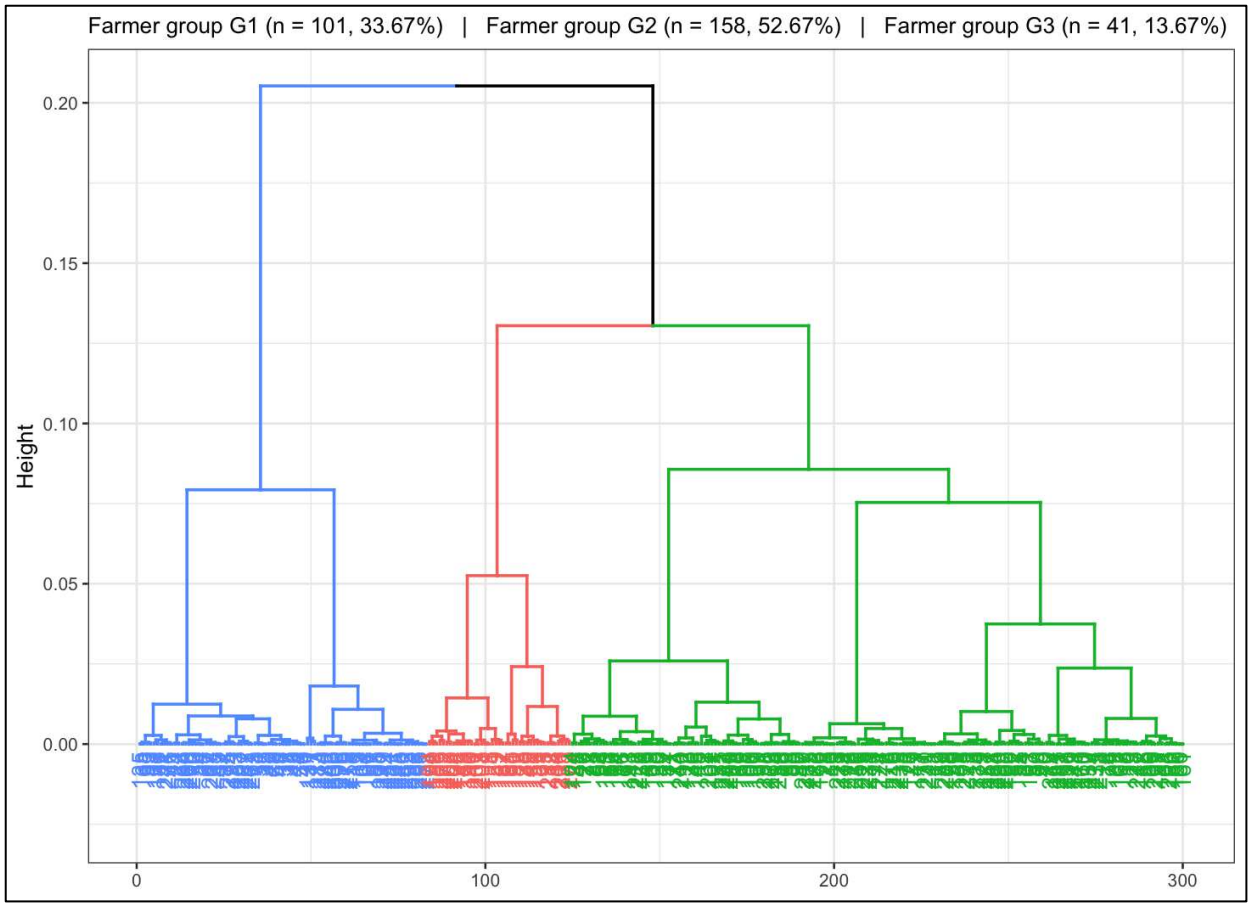


Fig. 2 Factorial map of the multiple correspondence (MCA) analysis of farmers' sociodemographic characteristics

Active modalities are shown in dark red, supplementary modalities (commune, production environment and ethnicity) in green, and individual farms (n=300) in grey



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239 **Fig. 3** Dendrogram from hierarchical clustering on the MCA factor coordinates

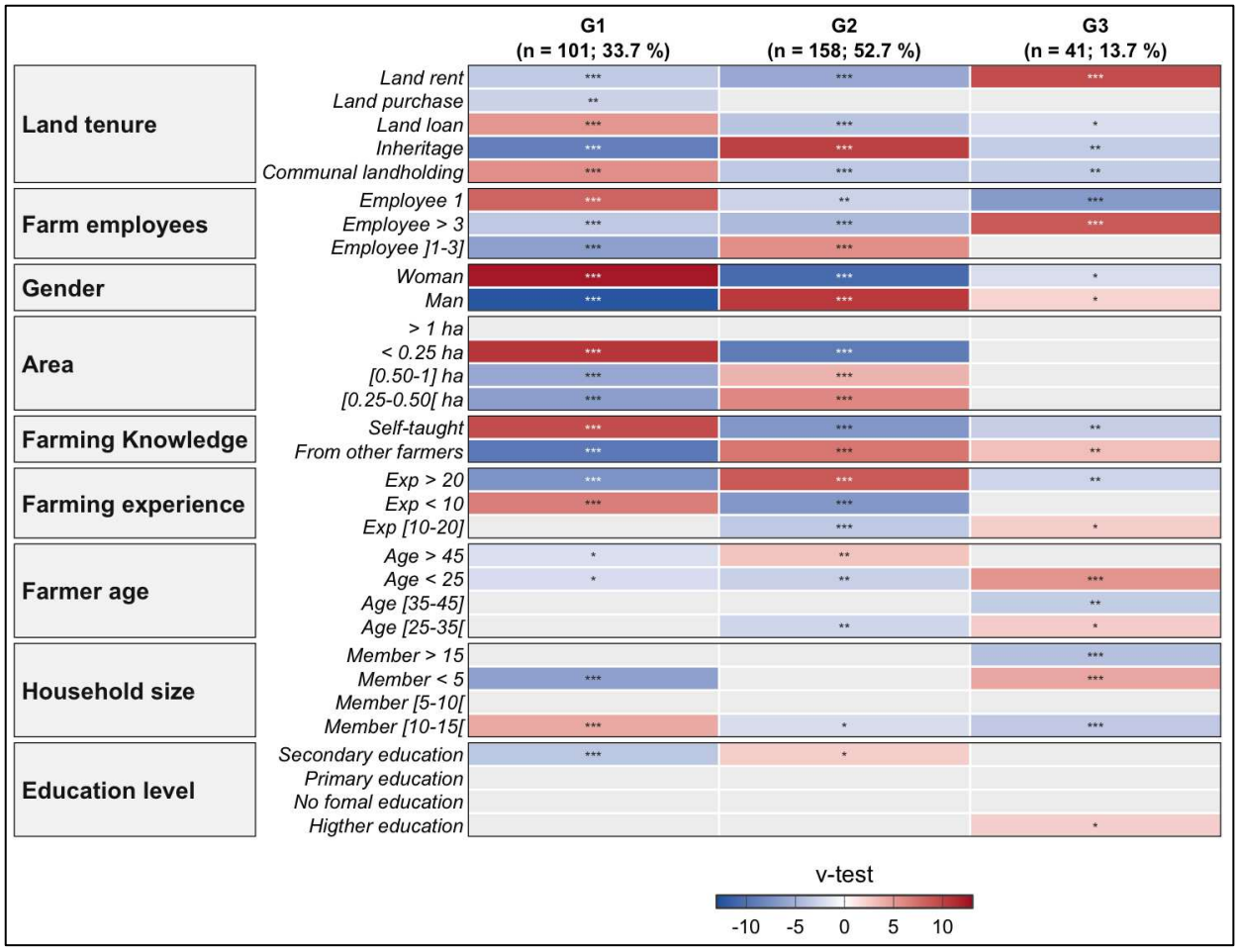


Fig. 4 Characterisation of the three farm types

V-test positive values (red) indicate over-representation and negative values (blue) under-representation relative to the full sample. *p < 0.05; **p < 0.01; ***p < 0.001

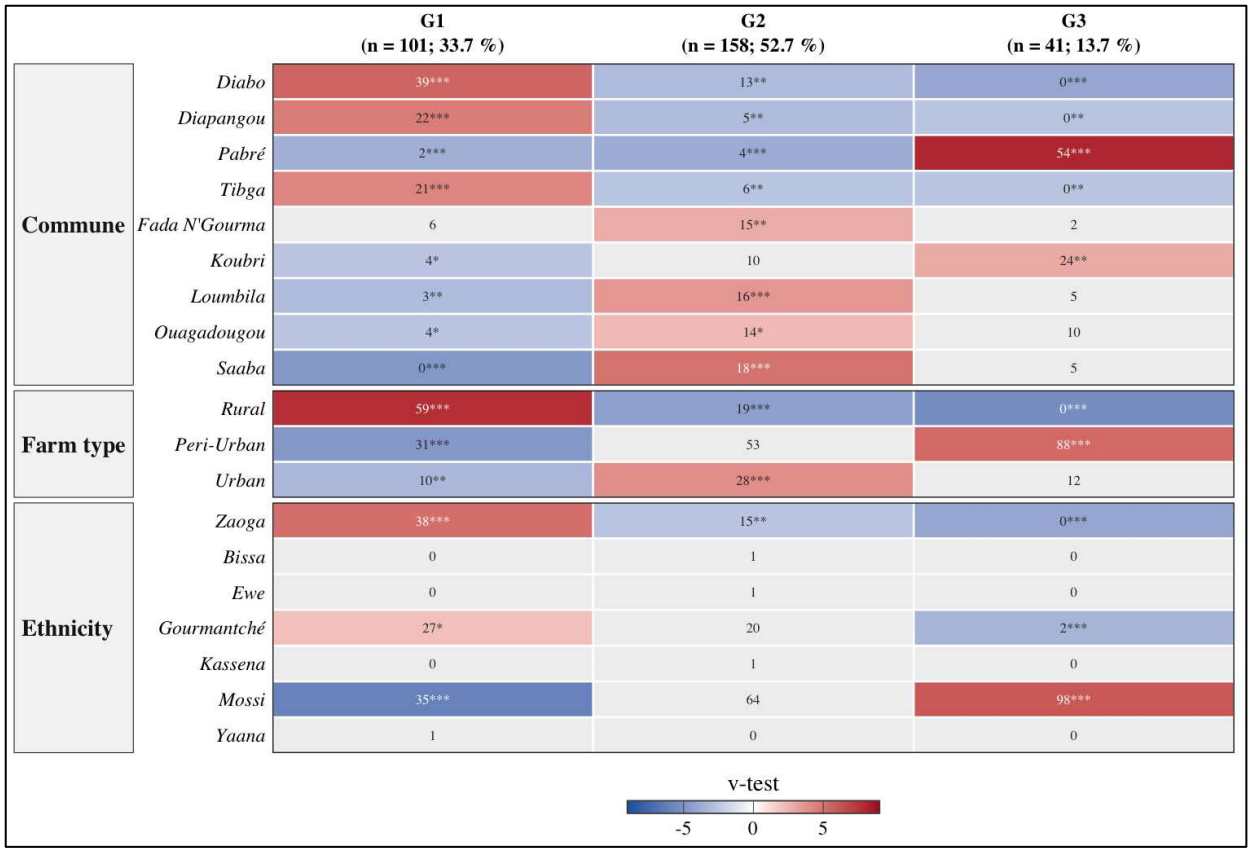


Fig. 5 Distribution of the three farm types across supplementary variables
Values are percentages of farms within each group; cell colour represents the corresponding v-test. *p < 0.05; **p < 0.01; ***p < 0.001

3.2. Farming practices across farm types

Twelve of the 24 practice modalities differed significantly among farm types (Table III). The largest differences concerned irrigation. Micro-irrigation was used by 70.7% of G3 farmers, compared with only 3.0% of G1 and 5.1% of G2 farmers ($p < 0.05$), whereas surface irrigation showed the opposite pattern, with 91.1% of G1 and 93.7% of G2 farmers using this method compared with 26.8% of G3 farmers (Table III). Water sources also differed among groups. Borehole use was most frequent in G1 (42.6%) and least frequent in G2 (7.0%), while reservoirs were the main water source for G2 farmers (82.3%) ($p < 0.05$; Table III).

Cropping seasons also varied among farm types. Hot dry-season production was reported by 96.0% of G1 and 91.8% of G2 farmers, compared with 51.2% of G3 farmers, whereas rainy-season production increased from 21.8% in G1 to 38.6% in G2 and 65.9% in G3 ($p < 0.05$; Table III). In contrast, fertiliser use was relatively similar across groups. Manure, NPK fertiliser and urea were widely used by all farm types, with no significant differences among groups ($p > 0.05$; Table III). Moreover, no

significant differences were observed in the crop growth stages targeted by pesticide applications ($p > 0.05$; Table III).

Synthetic pesticide use was widespread across all farm types, exceeding 95% in each group, with no significant between-group difference ($p > 0.05$; Table III). Some pesticide-management practices nevertheless varied among groups. Pesticide mixing was most frequent in G2 (72.2%), compared with 53.5% in G1 and 56.1% in G3, while crop rotation was less frequent in G3 (56.1%) than in G1 (75.2%) and G2 (77.2%) ($p < 0.05$; Table III). Evening pesticide application decreased from 91.1% in G1 to 68.4% in G2 and 43.9% in G3, although this difference was not significant ($p > 0.05$). Conversely, an unspecified application period was reported more frequently in G3 (46.3%) than in G2 (29.1%) and G1 (6.9%) ($p < 0.05$; Table III).

Crop composition differed significantly among farm types (Chi-2 = 262.11, $p < 0.05$; Fig. 7). A total of 29 crop species were recorded. G1 and G2 cultivated a relatively broad and similar range of crops, dominated by onion, tomato, cabbage, amaranth, eggplant, African eggplant, lettuce and okra. Onion and tomato were most prominent in G1, whereas onion and cabbage predominated in G2. In contrast, G3 cultivated a narrower range of crops, with chilli pepper more frequent than the other crops recorded in this group, while most remaining species occurred at relatively low frequencies (Fig. 7).

Table 3 Farming practices of the three farm types

Category	Practice	G1 (%)	G2 (%)	G3 (%)	Chi-2	P-value	Sig.
Cropping season	Hot dry	96.0	91.8	51.2	59.38	< 0.001	***
	Cold dry	100	99.4	85.4	31.64	2.9E-5	***
	Rainy (humid)	21.8	38.6	65.9	24.93	6.0E-6	***
Water source	Borehole	42.6	7.0	29.3	46.99	< 0.001	***
	Reservoir	52.5	82.3	65.9	26.44	3.0E-6	***
	Well	5.0	10.8	4.9	3.45	0.196	ns
Irrigation mode	Micro-irrigation	3.0	5.1	70.7	135.63	< 0.001	***
	Sprinkler irrigation	5.9	1.3	2.4	4.67	0.083	ns
	Surface irrigation	91.1	93.7	26.8	112.56	< 0.001	***
Fertilisation	Manure	97.0	98.1	95.1	1.16	0.412	ns
	NPK	98.0	96.8	92.7	2.60	0.412	ns
	Urea	94.1	83.5	82.9	6.72	0.104	ns
Crop stage treated	Nursery	96.0	88.6	82.9	6.88	0.076	ns
	Vegetative growth	99.0	98.7	100	0.53	1.000	ns
	Flowering	95.0	89.2	82.9	5.36	0.076	ns
	Fruiting	95.0	93.7	82.9	6.80	0.076	ns
	Maturation	94.1	88.0	80.5	5.84	0.076	ns

Treatment period	Morning	57.4	60.1	41.5	4.65	0.098	ns
	Midday	1.0	1.9	12.2	13.97	0.006	**
	Evening	91.1	68.4	43.9	35.81	< 0.001	***
	Unspecified	6.9	29.1	46.3	29.61	1.0E-5	***
Pest management	Synthetic pesticides	98.0	95.6	97.6	1.26	0.737	ns
	Pesticide mixing	53.5	72.2	56.1	10.47	0.011	*
Soil/crop management	Crop rotation	75.2	77.2	56.1	7.68	0.021	*

Values are percentages of farms within each type reporting each practice (G1, n = 101; G2, n = 158; G3, n = 41). p-values were adjusted using the Benjamini-Hochberg procedure. ns, not significant; *p < 0.05; **p < 0.01; ***p < 0.001

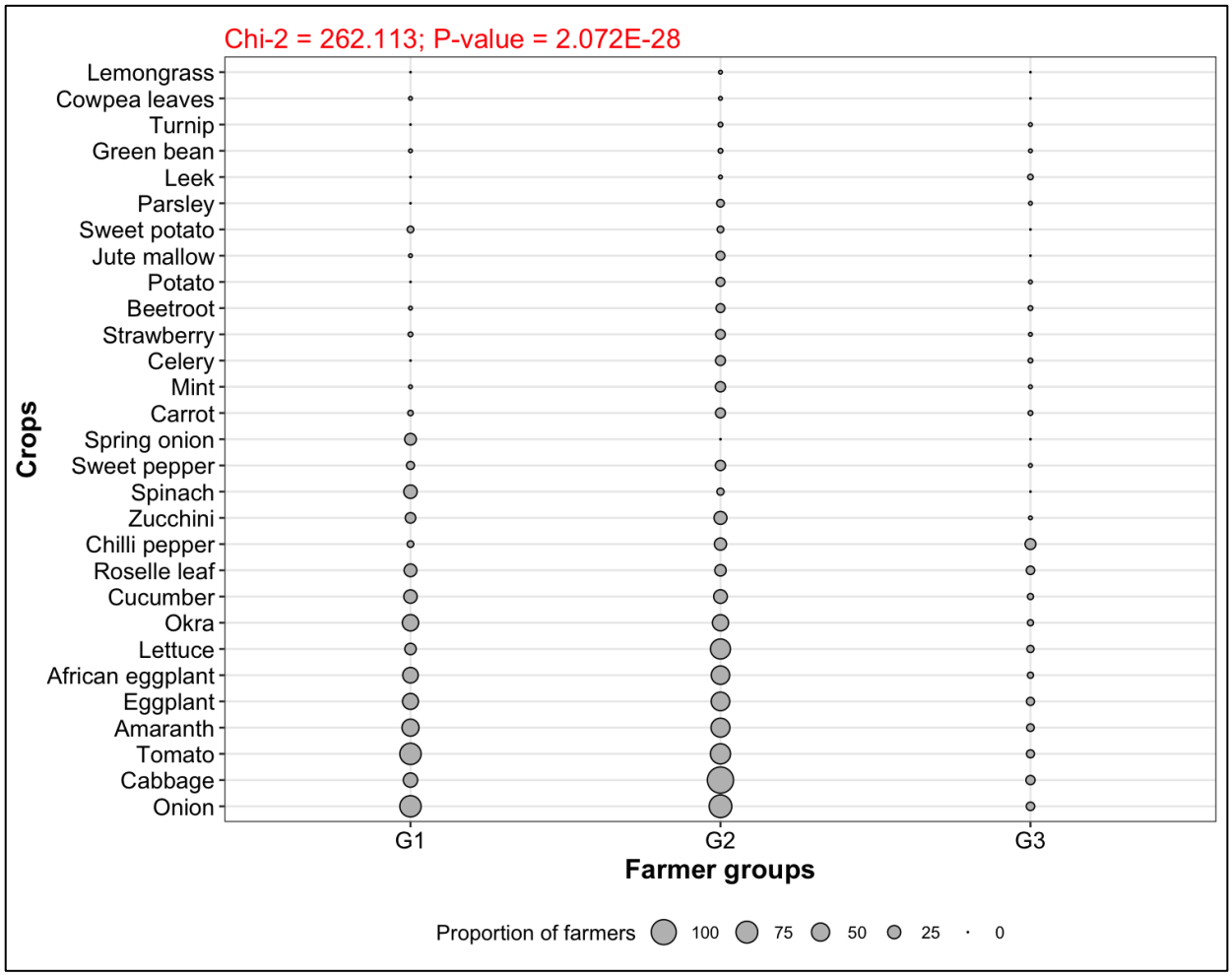


Fig. 6 Crops grown across farm types
Bubble size represents the percentage of farmers within each group cultivating each crop

3.3. Phytosanitary management across farm types

Insecticides were the most widely reported pesticide type across all three farm types (95 %), with all farmers using at least one insecticidal product (Fig. 8). Acaricides were also frequently reported, particularly in G1 (> 75 %), while herbicides were used by

more than half of the farmers in each group. Fungicide use was comparatively low and was almost absent in G1, although somewhat more frequent in G2 and G3.

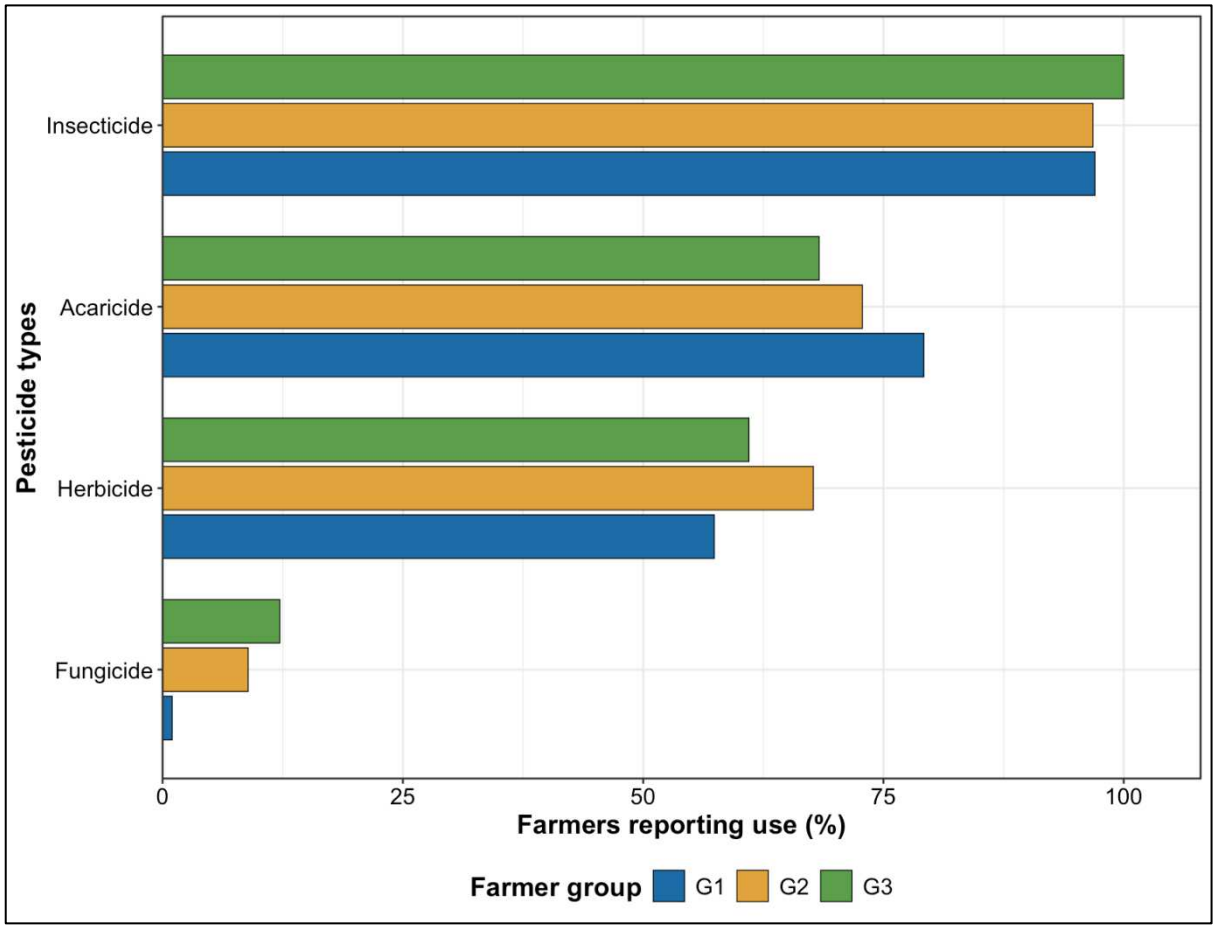


Fig. 7 Pesticide types reported by farm type
Values represent the percentage of farmers in each group reporting at least one product of each pesticide type

The organisms targeted by pesticide treatments were predominantly insect and mite pests (Fig. 9). Sucking pests and caterpillars were targeted by nearly all farmers, followed by mites. Leafminers were more frequently reported as treatment targets in G1 than in G2 and G3. Among weeds, grasses were the most frequently targeted group, followed by broadleaf weeds and sedges. Grasshoppers, termites and beetles were less frequently reported, although beetles were relatively more common targets in G3. Fungal pathogens and fruit flies were rarely reported.

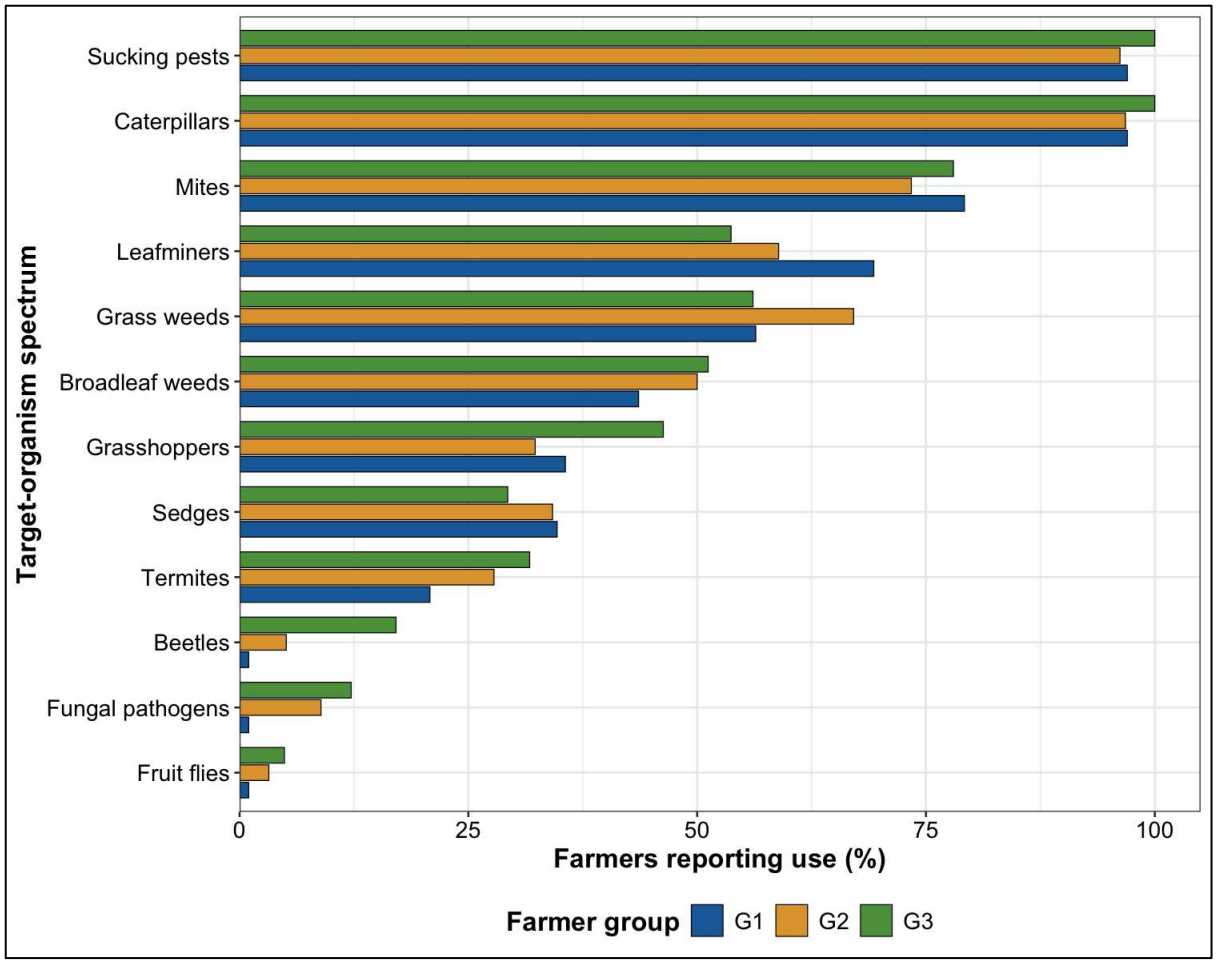


Fig. 8 Pest and weed groups targeted by pesticide treatments across farm types Values represent the percentage of farmers in each group reporting treatment against each target group

The 15 most frequently reported active ingredients were dominated by insecticides (Fig. 10). Lambda-cyhalothrin and emamectin benzoate were the most widely used, each reported by approximately 80-93% of farmers across the three groups. Acetamiprid and abamectin were also common, but their use decreased from G1 to G3. Acetamiprid was reported by approximately 77%, 70% and 58% of farmers in G1, G2 and G3, respectively, while the corresponding values for abamectin were 73%, 64% and 51%. Methomyl, deltamethrin, haloxyfop-R-methyl and etoxazole were also more frequently reported in G1, whereas butachlor was more common in G2 and G3.

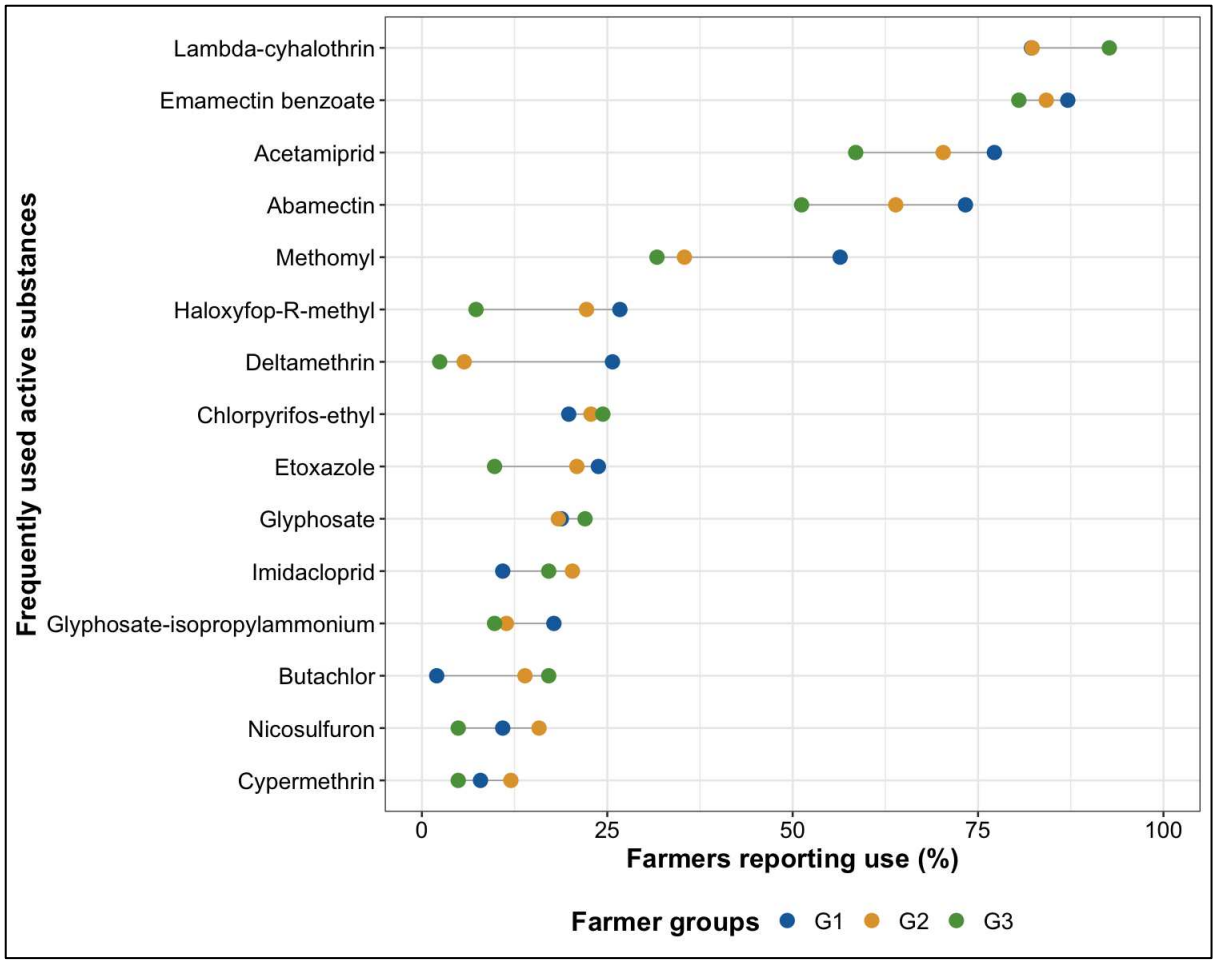


Fig. 9 Most frequently reported pesticide active ingredients across farm types Values represent the percentage of farmers in each group reporting each active ingredient

A total of 25 pesticide chemical classes were identified, of which 16 occurred in G1, 25 in G2 and 21 in G3 (Fig. 11). Avermectins (92-94%), pyrethroids (86-98%) and neonicotinoids (66-81%) were the most widely represented classes across all groups. Oxime carbamates declined from 56% in G1 to 35% in G2 and 32% in G3, with similar patterns observed for aryloxyphenoxypropionates and diphenyl oxazolines. In contrast, organophosphates increased from 24% in G1 to 30% in G2 and 42% in G3. Several less frequently reported classes, including phenylpyrazoles, chloroacetanilides, bipyridyliums and oxadiazines, were proportionally more common in G3. Biological and botanical pesticide products were rarely reported in any of the three groups.

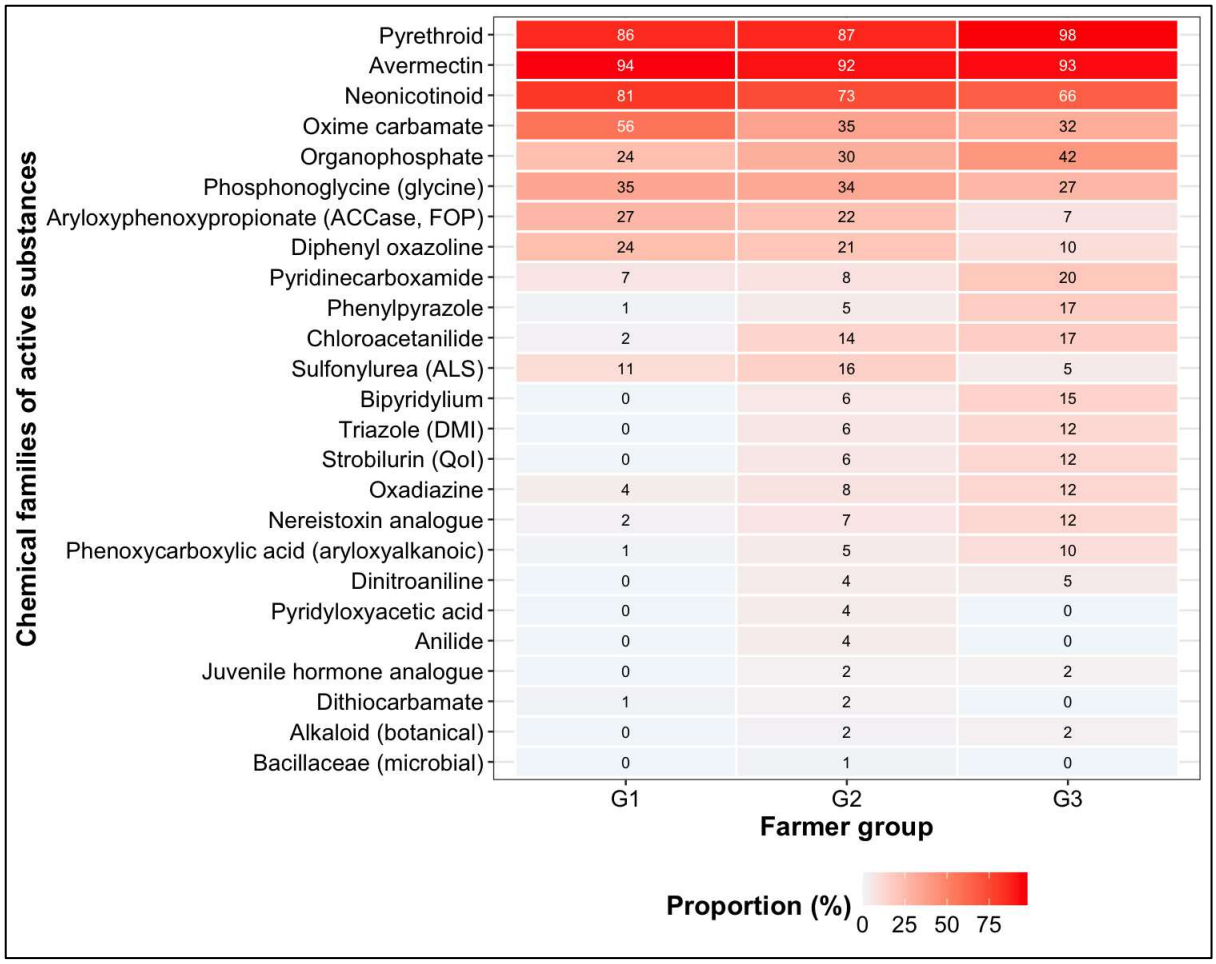


Fig. 10 Chemical classes of pesticide active ingredients reported across farm types Values represent the percentage of farmers in each group reporting at least one product belonging to each class

The crop identified as receiving the most pesticide treatments differed markedly among farm types (Fig. 12). Overall, cabbage was most frequently identified as the most treated crop (42.1%), followed by tomato (23.7%), although clear differences occurred among groups. In G1, tomato was most frequently identified as the most treated crop (44.0%), followed by cabbage (18.0%), onion (10.0%) and okra (8.0%). In G2, cabbage predominated, accounting for 61.4% of responses, followed by tomato (13.3%); no other crop exceeded 6.3%. G3 showed a contrasting pattern, with chilli pepper most frequently reported (39.0%), followed by cabbage (26.8%), tomato (14.6%) and eggplant (9.8%). The distribution of crops identified as receiving the most pesticide treatments differed significantly among farm types (Chi-2 = 173.52, $p < 0.001$; Table IV).

Table 4 Crops identified as receiving the most pesticide treatments across farm types

Crop	G1 (%)	G2 (%)	G3 (%)	Total (%)
Cabbage	18	61.4	26.8	42.1
Tomato	44	13.3	14.6	23.7
Chili pepper	0	1.3	39	6
Eggplant	4	5.7	9.8	5.7
Amaranth	5	6.3	0	5
Onion	10	0.6	2.4	4
Zucchini	6	3.2	0	3.7
Okra	8	1.3	0	3.3
Lettuce	0	1.9	2.4	1.3
Cucumber	3	0.6	0	1.3
Sorrel	1	0.6	2.4	1
Jute mallow	0	1.3	0	0.7
Purple eggplant	1	0.6	0	0.7
Strawberry	0	1.3	0	0.7
Bell pepper	0	0.6	0	0.3
Carrot	0	0	2.4	0.3
Chi-2		173.52		
P-value		P < 0.001		

Values represent the percentage of farmers within each group identifying each crop as the most frequently treated.

The diversity of crops identified as receiving the most treatments also differed descriptively among groups (Table IV). G2 included the greatest number of crop species (S = 15), compared with 10 in G1 and 8 in G3. Thus, responses were more evenly distributed among crops in G1 and G3 than in G2, despite the greater number of crop species recorded in G2.

Table 5 Diversity of crops identified as receiving the most pesticide treatments within each farm type

Farm type	Most frequently treated crop	Crop richness (S)
G1	Tomato (44.0%)	10
G2	Cabbage (61.4%)	15
G3	Chilli pepper (39.0%)	8

Finally, comparison of the products reported by farmers with their registered crop uses showed that pesticides used in market gardening were registered across a broad range of crop categories (Fig. 13). All farmers reported at least one product registered for vegetable crops. However, more than 90% of farmers in each group also reported products whose registered uses included fruit crops and cotton. Products registered for cereals and legumes were also common, whereas those registered for rice and

maize were reported less frequently. Products registered for sugarcane, perennial crops or broadly across crop categories were comparatively uncommon.

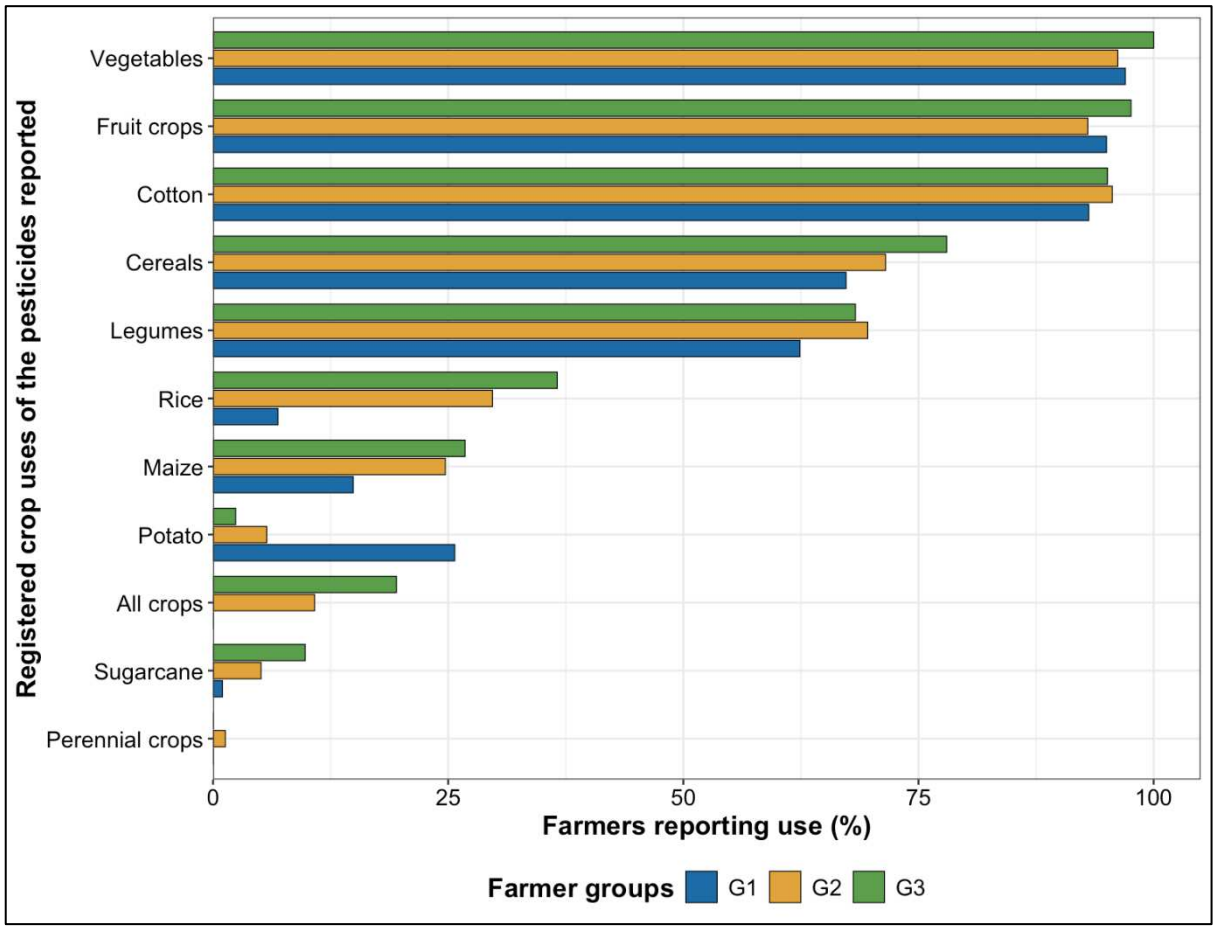


Fig. 11 Registered crop uses of pesticide products reported in market-garden Values represent the percentage of farmers within each farm type reporting at least one product registered for the indicated crop category

4. Discussion

4.1. Influence of farmers' sociodemographic profiles on farm-type differentiation

The identification of three distinct farm types supports our first hypothesis that market-gardening farms can be grouped into a limited number of contrasting farmer profiles. Farm heterogeneity has been widely documented in urban and peri-urban agriculture in West Africa, where access to land, farm size, labour availability, resource endowment and production orientation contribute to differences among farming systems [31]. Indeed, in Burkina Faso, Ouédraogo et al [20] identified contrasting vegetable-farm types around Bobo-Dioulasso, while [32] showed that market-gardening farms differed along an urban, peri-urban and rural gradient associated with

their economic performance. However, the present typology was constructed exclusively from farmers' sociodemographic characteristics, with management practices excluded from the classification. This distinction is important when the objective is to examine whether management practices differ among farmer profiles, because the variables used to construct the typology should be independent of the outcomes subsequently compared [28,29,35]. A similar approach was adopted by Berre et al [48] in Burkina Faso, where farm-household structure and management practices were classified separately. Moreover, the variables used to build a farm typology should be selected according to its analytical purpose rather than simply according to data availability [29,34].

G1 combined small farm size, limited labour and predominantly communal or borrowed land, and was largely composed of women in rural areas. This profile is consistent with evidence that access to productive resources depends not only on formal rights but also on social relations and authority [13]. Women remain disadvantaged in landownership across many African countries [14], and in Burkina Faso their access to agricultural land has historically relied heavily on secondary or negotiated arrangements [49–51]. Similar constraints on land, labour and irrigation have been reported among women engaged in vegetable production in West African countries [52].

These patterns should not, however, be attributed to gender alone. Household size and composition also affect cultivated area and labour availability over the household life cycle [53]. Because women's access to land may itself depend on marriage and household position [49], gender and life-cycle effects cannot be separated with cross-sectional data. G1 is therefore better interpreted as a composite profile of restricted access to land and labour rather than as evidence of an isolated gender effect.

The contrast between G2 and G3 suggests two different pathways into commercial vegetable production. G2 represented a more established model based on inherited land, accumulated experience and moderate labour use. G3, in contrast, comprised younger and more educated farmers, predominantly peri-urban, who rented land and employed larger workforces. Comparable interactions among tenure, urban proximity and production strategy have been reported by several authors [11,32]. The G3 profile may nevertheless involve greater tenure insecurity, since peri-urban vegetable production is often exposed to competition from urban development [52]. Farm types

should therefore be viewed as combinations of farmer characteristics, resource access and production environment rather than as evidence of independent effects of age, education, gender or tenure.

4.2. Relationship between farm types and cropping practices

Irrigation most clearly differentiated the three farm types. Micro-irrigation was strongly associated with G3, whereas G1 and G2 relied mainly on surface irrigation. This pattern is consistent with studies showing that adoption of irrigation technologies depends not only on technical performance but also on investment capacity, resource availability and local production conditions [54–56]. In West Africa, cost remains a major constraint to drip-irrigation adoption [56,57]. The greater education, labour availability and peri-urban concentration of G3 are therefore compatible with its higher use of micro-irrigation, although their respective effects cannot be distinguished.

Water sources also varied among groups, with G2 relying mainly on reservoirs and G1 more frequently on boreholes. Because water infrastructure is strongly site-dependent, these differences likely reflect production environment as much as farmer choice. This reinforces the need to interpret farm types as socio-spatial profiles rather than purely individual categories.

Cropping calendars and crop choice showed similar differentiation. G1 and G2 were concentrated in the hot dry season, whereas G3 engaged more frequently in rainy-season production and cultivated a narrower crop portfolio, with chilli pepper particularly prominent. G3 farmers also rotated crops less often. Rainy-season vegetable production in Burkina Faso has been associated with rainfall variability, irrigation opportunities and market conditions [36,58], while crop choice and market participation among West African vegetable growers are linked to education, credit access and expected returns [59,60]. G3 therefore appears consistent with a more specialised and market-oriented production strategy.

G3 farmers were younger; their narrower crop portfolios and less frequent rotations may also reflect shorter experience in market gardening. Farm types are not necessarily static; in southern Mali, a substantial proportion of farms shifted between types over time [61]. Fertiliser use, by contrast, varied little among farm types. Indeed, manure, NPK and urea were widely used across all groups, as reported in several

studies in West Africa [20,36]. Fertilisation thus appears to be a common feature of intensive vegetable production rather than a strong marker of farm type.

4.3. Pesticide use and management across farm types

Synthetic pesticide use exceeded 95% in all three groups, indicating that chemical crop protection is nearly universal among the commercial market gardeners surveyed. Similar patterns have been reported in Burkina Faso [18,36], while residues including lambda-cyhalothrin and acetamiprid have been detected in sold vegetables [62]. This finding is also consistent with the broader association between agricultural intensification and pesticide use [3]. Herbicides were likewise widely used, reflecting their rapid expansion in developing countries as product prices have fallen and rural wages have increased [16].

Differences among groups were more evident in pesticide handling than in pesticide use itself. Mixing was common across all farm types and particularly frequent in G2. Similar practices have been linked in West Africa to savings in labour, time and cost [63], while financial constraints have also been associated with pesticide mixing and repackaging [26]. In G2, crop composition can be explained by the fact that cabbage was the most frequently treated crop, and *Plutella xylostella* is a major brassica pest with widespread insecticide resistance [64]. Mixing may therefore reflect both economic motives and attempts to maintain efficacy, although the present data cannot distinguish these mechanisms.

Application timing also differed among farm types. Evening spraying was most common in G1, whereas G3 farmers more often reported no fixed spraying period. For G1, this may partly reflect women's time constraints, since agricultural activities are often organised around competing household and farming responsibilities [49,65]. In G3, the absence of a fixed spraying period may be associated with greater use of hired labour, but this remains speculative because the identity of applicators was not directly analysed. Future surveys should distinguish farm managers from workers responsible for spraying, particularly when assessing occupational exposure. The crop receiving the most treatments also differed by farm type and broadly reflected each group's crop portfolio. Cabbage was the most frequently treated crop overall, consistent with the high insecticide pressure associated with *P. xylostella* [64]. Tomato predominated in

G1, where leafminer control and acaricide use were also more frequent; tomato production in Africa is increasingly challenged by *Tuta absoluta* [19]. These results indicate that pesticide pressure is partly mediated through crop choice, which itself differs among farm types.

Crop stages treated did not differ among groups, and more than 80% of farmers reported treatments at crop maturity. This is particularly relevant because compliance with pre-harvest intervals directly affects residue levels in harvested produce. Together with pesticide residues already detected in vegetables from markets [62], these findings support the need for residue monitoring. Farm types may help identify priority crop-farmer combinations for sampling, particularly tomato in G1-type farms, cabbage in G2-type farms and chilli pepper in G3-type farms. Product portfolios also differed descriptively among groups. Avermectins, pyrethroids and neonicotinoids formed the dominant core across all farm types, with lambda-cyhalothrin and emamectin benzoate among the most frequently reported active ingredients. Lambda-cyhalothrin was also prominent in an earlier survey of tomato growers in Burkina Faso [18]. Heavy reliance on a limited number of mode-of-action groups is inconsistent with resistance-management strategies based on rotating modes of action [66], particularly for pests such as *P. xylostella* and *T. absoluta*, which have well-documented resistance problems [19,64].

Differences in potentially hazardous products also warrant attention. Oxime carbamates were more frequent in G1 and included methomyl, classified by WHO as highly hazardous (Class Ib) [67], whereas organophosphate use increased toward G3. Occupational risks associated with organophosphate handling are well documented [23]. Because differences in active ingredients and chemical classes were not tested formally, these patterns should remain descriptive. Nevertheless, they suggest that greater education and resource availability do not necessarily translate into narrower or less hazardous pesticide portfolios. Since health and ecological risks vary substantially among active ingredients [22], interventions should focus on the products actually used within each farm type rather than on sociodemographic characteristics alone.

Label information raises a related regulatory issue. More than 90% of farmers in each group used at least one formulation whose authorised uses included fruit crops or cotton. However, it is consistent with earlier reports of cotton pesticides being applied

to vegetables in Burkina Faso [20] and with weak post-registration control in West African pesticide markets [17].

Biological and botanical products remained uncommon across all groups, including G3. Their limited adoption among the better-resourced farmers suggests that barriers may extend beyond individual capacity to include product availability, cost, advisory support and confidence in efficacy. Similar constraints have been reported in West Africa [26,68,69], while inadequate technical support remains a major barrier to IPM adoption in developing countries [24]. Reducing dependence on synthetic pesticides will therefore require more than farmer training; reliable access to effective alternatives and sustained advisory support are also needed.

4.4. Implications for sustainable development

The classification of farms in this study indicates that progress towards the Sustainable Development Goals (SDGs) is likely to be uneven [30]. Regarding SDG 5, Group 1 (G1) is characterised by predominantly female management, small land areas, limited labour, and communal or borrowed land. Consequently, interventions that presume uniform access to land, water, and labour are unlikely to benefit these farmers equitably. Ensuring secure land access and affordable irrigation could contribute to achieving target 5.a of SDG 5. However, our cross-sectional data do not permit the isolation of gender effects from those related to household position. In relation to SDG 2, micro-irrigation is predominantly found in Group 3 (G3), while surface irrigation accounts for over 91% in Groups 1 (G1) and 2 (G2). Thus, water-efficient technologies are currently limited to farms with better resources.

In relation to Sustainable Development Goals (SDG) 3 and 12, the use of synthetic pesticides surpassed 95% across all categories, with mixing being a prevalent practice. Over 80% of farmers reported applying treatments at the stage of crop maturity, and more than 90% utilised at least one formulation authorised for use on fruit crops or cotton. These practices suggest potential risks for both applicators and consumers, as well as inadequate post-registration control, although this study did not measure exposure and residues. Consequently, efforts should focus on reducing pesticide risks, ensuring reliable access to effective alternatives, and providing

sustained advisory support across all profiles. Additionally, profile-specific measures should be implemented to address varying constraints [24,26].

5. Conclusion

This study shows that market-gardening systems in the Sudano-Sahelian zone of Burkina Faso encompass distinct farmer profiles that differ in both their sociodemographic characteristics and several aspects of crop and pesticide management. By constructing the typology independently of the practices subsequently analysed, the study provides a clearer assessment of how farmer heterogeneity is associated with management decisions.

Three contrasting farm types were identified. Moreover, the farm types differed in cropping season, water source, irrigation method, crop composition and crop rotation, whereas fertiliser use and several other production practices were broadly similar across groups. Synthetic pesticide use was widespread and did not differ significantly among farm types, indicating that reliance on chemical crop protection is widespread across farmer profiles. In contrast, pesticide mixing, application timing, and the crop receiving the most frequent treatments varied among groups. Differences were also observed in the profiles of active ingredients and chemical classes, although these patterns remain descriptive because they were not formally tested.

These findings have direct implications for agricultural extension. Recommendations related to irrigation, crop diversification, crop rotation and specific pesticide-management practices should be adapted to the constraints and resources of different farmer profiles. By contrast, integrated pest management, safer pesticide uses and improved access to effective alternatives to synthetic pesticides are relevant across the market-gardening sector. In contrast, integrated pest management, the safer application of pesticides, and enhanced access to effective alternatives to synthetic pesticides are pertinent throughout the market-gardening sector. By focusing extension efforts in this manner and extending pesticide-risk reduction to all farmer profiles, these strategies would contribute to Sustainable Development Goals 2, 3, 5, and 12. This would be achieved by promoting safer vegetable production and addressing the resource constraints encountered by women farmers.

The present study characterises reported pesticide use but does not determine whether these practices result in environmental contamination or consumer exposure. Future research should therefore combine farm typologies with measurements of pesticide residues in agricultural soils, irrigation water, surface and groundwater, and harvested vegetables. Linking residue concentrations to specific active ingredients, crops, application practices and farm types would help identify potential contamination pathways and priority crop pesticide combinations. Such evidence would strengthen environmental and food-safety risk assessment and support more targeted pesticide-risk reduction strategies in Burkina Faso. It would also help monitor progress towards Sustainable Development Goals in the vegetable sector.

Acknowledgements

This study was carried out with the support of *Projet Communautaire de Relèvement et de Stabilisation au Sahel-Burkina Faso* (PCRSS-Burkina). We would also like to thank the local authorities and farmers who gave their consent to enable this study to be carried out.

Author contributions

S.Y.D. wrote the main manuscript text. All authors reviewed and corrected the manuscript.

Funding

Projet Communautaire de Relèvement et de Stabilisation au Sahel-Burkina Faso (PCRSS-Burkina)

Data availability

Data will be made available upon reasonable request from the corresponding author.

Declarations

Ethics approval

Ethical approval for this study was obtained from the Ethics Committee of University Joseph KI-ZERBO, Burkina Faso (Ref No: 2024/0190/MESRI/SG/UJKZ/P).

Ethical accordance

The study was conducted in accordance with the ethical guidelines of the Ethics Committee of University Joseph KI-ZERBO.

Consent to participate

This study was conducted with farmers' informed consent and with formal approval from local authorities in all study Communes.

Clinical trial number

Not applicable.

Consent to publish

Not applicable.

Competing interests

The authors declare no competing interests.

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