Agriculture, Ecosystems and Environment 259 (2018) 159–167

Contents lists available at ScienceDirect

Agriculture, Ecosystems and Environment

journal homepage: www.elsevier.com/locate/agee

Farmers' perceptions of crop pest severity in Nigeria are associated with landscape, agronomic and socio-economic factors

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ARTICLE INFO

Keywords:
Pest regulation
Household survey
Crop management
Land use
Production situations
Africa

ABSTRACT

Insect pests are a major cause of crop yield losses around the world and pest management plays a critical role in providing food security and farming income. This study links Nigerian farmers' perceptions of pest severity to the landscape, agronomic, biophysical, and socio-economic context in which agricultural production takes place. A farm household survey was conducted during 2012–2013, collecting data on household characteristics, cropping systems, pest severity and pest management from 805 households in 12 states of Nigeria. Village characteristics and land use information were collected from an accompanying semi-structured village survey. Reported pest severity was negatively associated with the proportions of forest and unused land at the landscape scale. This finding suggests the existence of pest suppressive effects of a diverse landscape under African smallholder agriculture settings, confirming findings of more industrial and larger scale agroecosystems in the temperate zone. Application of fertilizers (chemical and manure) was negatively related to reported pest severity. Moreover, reported pest severity was lower in mixed-cropping systems than in mono-cropping systems, reinforcing the idea of a pest suppression benefit of diverse cropping systems. In conclusion, our findings suggest that the presence of non-crop areas in the landscape and the diversification of agroecosystems may be a viable strategy for smallholder farmers to manage pests with limited reliance of chemical insecticides in Nigeria, but that actual pest management decisions are influenced by a wide range of context-specific factors. The paper adds new evidence on the relationship between different production situation characteristics and pest severity for Nigeria, based on which policy implications are discussed.

1. Introduction

Insect pests are a major cause of crop yield losses around the world (Oerke, 2006) and an important cause of food insecurity in developing countries (Zakari et al., 2014). Farmers make crop and pest management decisions within the realm of their production situations, i.e., the physical, biological, technical, social, and economic context in which production takes place (Penning de Vries, 1982; Savary et al., 2006a,b), and their decisions in turn shape their production situations. While the interdependence between the susceptibility to pest infestation and the production situation has been demonstrated before (Allinne et al., 2016; Avelino et al., 2006; Savary et al., 2006a,b; Savary et al., 2017), little is known about the relationship between production situations and farmer reported pest severity on common crops in Nigeria. Analyzing the perceptions of farmers on pest severity within the context of their production situation can provide important new insights in the ways to encourage ecologically-based pest management attitudes and practices.

The management of pests has important implications for African agriculture where the majority of the farmer community consists of smallholder farmers with low agricultural productivity (Bature et al., 2013). In Nigeria, insect pests and plant diseases are major yield reducing factors, threatening food security and farmers' incomes. For example, insect pests and diseases in yams resulted in a 25% mean annual yield loss (Tobih et al., 2011; Amusa et al., 2003) and 25–30% of yield loss of cocoa was attributed to the brown cocoa mirid alone (Ndubuaku and Asogwa, 2006). While Nigerian farmers are aware of the availability of several methods of pest control, including chemical, biological and traditional cultural control methods, farmers commonly do not actively control pests in their field crops (Alghali, 1991; Bottenberg, 1995; Banjo et al., 2003; Ofor et al., 2009). Farmers who actively manage pests rely primarily on chemical insecticides, but can

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https://doi.org/10.1016/j.agee.2018.03.004
Received 13 November 2016; Received in revised form 6 March 2018; Accepted 8 March 2018
Available online 21 March 2018

be constrained by the cost and availability of insecticides (Banjo et al., 2003). Traditional and cultural pest management methods include sprinkling of wood ash on plants, manual removal of pests, beating the crop with branches, application of kerosene/ash sprays, crop rotation, intercropping, and leaving land fallow are cheap and readily available, but their impact may be limited and some of these methods are labor intensive (Bottenberg, 1995; Alghali, 1991; Amusa et al., 2003; Banjo et al., 2003).

The ecosystem service of pest regulation provided by natural enemies has been estimated to represent a worldwide value of 100–400 billion USD per year (Costanza et al., 1997; Pimentel et al., 1997). The effectiveness of natural enemies in suppressing pest populations relies on both agricultural management at the field scale, and the structure, composition, and functioning of the surrounding landscape (Tscharntke et al., 2005; Bianchi et al., 2006; Chaplin-Kramer et al., 2011; Veres et al., 2013). However, little information is available on the effect of landscape factors on natural pest control in developing countries, and Africa in particular. Ironically, natural pest regulation is a critical ecosystem service for poor smallholder farmers who have limited economic access to external inputs and therefore rely on ecosystem services provided by agroecosystems and their surrounding landscapes. Promoting natural pest regulation may not only improve productivity and profit, but may also reduce farmers' dependence on the use of chemical insecticides, which can have negative impacts on human health and the environment (Pimentel et al., 1997; Naylor and Ehrlich, 1997; Antle and Pingali, 1994), and negatively affect natural enemies that suppress pest populations (Eveleens, 1983; Hansen, 1986). The extent to which the natural enemy community is conserved and utilized to substitute or complement chemical insecticides-based pest management has important implications for the socio-economic and environmental resilience of farming systems in developing countries.

The development of effective policies to support more sustainable pest management requires a better understanding of the factors that determine farmers' pest management decision making within the landscape, agronomic, socio-economic and biophysical context of farming systems (Savary et al., 2017). Previous studies have examined the effects of socio-economic factors on the likelihood of using production inputs such as fertilizers and insecticides (e.g., Nkamleu and Adesina, 2000; Zhou et al., 2010; Waithaka et al., 2007), but studies that also incorporate agronomic and ecological factors in a household analysis are scarce. The aim of this paper is to assess the ecological, agronomic, and socio-economic factors that are associated with farmer perceptions of the severity of pests in their field crops in Nigeria. The study comprised three agro-ecological zones spanning a 1000 km North-South gradient, 102 villages and 805 households. Factors associated with reported pest severity are identified and policy implications are discussed.

2. Materials and methods

2.1. Agro-ecological and socio-economic context

Nigeria encompasses semi-arid savanna ecosystems in the north and tropical forest ecosystems in the south (Aregheore, 2009). Amidst these diverse agroecological conditions there is also heterogeneity in ethnicity and cultures (Aregheore, 2009), as well as vast economic disparities between different regions of the country (Oxford Poverty and Human Development Initiative, 2015). After a period of marginal expansion from 1997 to 2007, the area of arable land is now declining (FAOSTAT, 2016a). Land degradation has been recognized as one of the most important natural resource management problems in Nigeria, constraining agricultural and rural development (FAO and ITPS, 2015; Odemerho, 1992; Titilola and Jeje, 2008). Meanwhile, the population has been steadily growing at an annual rate of around 2.8% (FAOSTAT, 2016a) and there has been a robust economic growth in the last decade (African Development Bank Group, 2015). Nevertheless, the proportion of the population that is multidimensionally poor is 53.3% nationally and 70% in rural areas, with remarkable regional variation (Oxford Poverty and Human Development Initiative, 2015).[1]

Nigeria's agricultural sector has a relatively high insecticide use as compared to other African countries. For instance, insecticide import by Nigeria accounted for 11% of the total import value for the whole of Africa in 2011 (FAOSTAT, 2016b). Despite a seven-fold increase in net pesticide imports from US$31 million to US$221 million between 1997 and 2012, progress on increasing cereal production (which is mainly used for domestic consumption) and per capita food supply has stagnated (FAOSTAT, 2016a). While the increase of pesticide inputs has contributed to the productivity growth of agricultural workers (FAOSTAT, 2016a), this has not been translated into significant food security gains. These findings question the effectiveness of strategies that are solely based on pesticides, and highlight the need for more sustainable pest management strategies that go beyond pesticide-based pest management.

2.2. Data collection

2.2.1. Sampling

Survey field work for this study was carried out in Nigeria during late 2012 – early 2013. The design of the field work was linked to the midline survey of an impact evaluation study conducted for the Nigeria Third National Fadama Development Project ("Fadama III" project) which covered all 37 Nigerian states (Appendix A). Using the sampling framework established for the Fadama III project, we adopted a stratified sampling approach by first selecting 12 states that covered the three primary agro-ecological zones (AEZs) in Nigeria: Sudan Savannah, Guinea Savannah, and Humid Forest (four states for each AEZ). These states have relatively high poverty rates based on the 2010 Nigeria poverty profile (National Bureau of Statistics, 2012) and a high incidence of conflicts over the use of common natural resources (Nkonya et al., Unpublished data). Northeastern states were excluded from consideration due to security concerns. In each of the 12 states, 6 to 10 villages were randomly selected from the midline survey sample (Appendix A). Finally, we randomly selected households from each of the villages, giving us a sample consisting of 851 households from 102 villages, with 34 villages in the Humid Forest zone, 36 in the Guinea Savannah, and 32 in the Sudan Savannah (Fig. 1). Village and household surveys were conducted in each selected village. After removing missing values, outliers and inappropriately measured responses, the final dataset used in the regression analysis contained data from 805 households. While this sampling strategy was not fully random across Nigeria (Appendix A), the sample provided comprehensive geographic coverage of the country and covers all three primary AEZs.

2.2.2. Survey instruments

In the farm household survey (see Appendix B for the household survey questionnaire), respondents were asked information on households' social and demographic characteristics, such as ethnicity, age and gender of household head, family size, and farm size, as well as detailed information on pest management. Each household was asked to report up to three main crops that were grown in the previous growing season, and to list up to two important insect pests for each crop. A field guide for insect pests, natural enemies, and pollinators in 15 main crops of Nigeria was developed to assist farmers identifying insect species. Perceived pest severity was expressed at a 3-level scale (1 = significant yield reduction, 2 = moderate yield reduction, and

[1] The global Multidimensional Poverty Index (MPI), developed by the Oxford Poverty & Human Development Initiative (OPHI), is an international measure of acute poverty covering over 100 developing countries. It complements traditional income-based poverty measures by capturing the severe deprivations that each person faces at the same time with respect to education, health and living standards (Alkire et al., 2016; OPHI, 2007–2016).

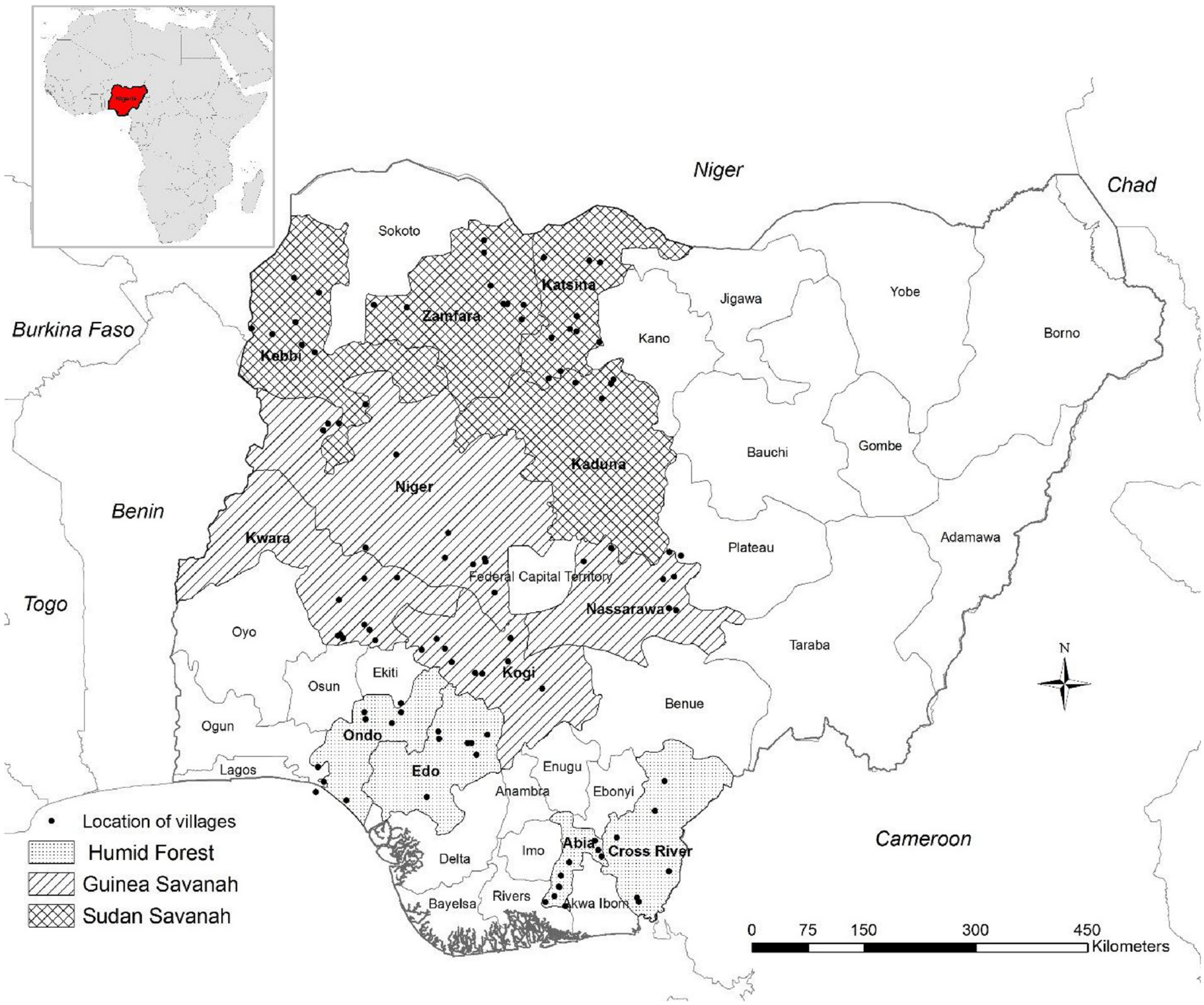

Fig. 1. Surveyed villages in 12 states across three agro-ecological zones in Nigeria.

3 = little or no yield reduction) for each reported insect pest. These data were complemented with data on management practices, such as irrigation, use of improved seeds, use of chemical fertilizer and manure, and cropping system (monocropping vs. mixed cropping) for each household from the Fadama III project survey. While the Fadama III survey was completed six months prior to our survey, and we cannot rule out changes in management practiced in these six months, this was the best possible information at hand.

Village level information was elicited using semi-structured group interviews conducted in local dialects, and included village characteristics (e.g., road access and distance to the nearest agro-chemical store), welfare indicators (e.g., the proportion of households in the village that had less than two meals a day), and prevalence of insecticide use (see Appendix C for the village survey questionnaire). A land cover and land use assessment exercise was conducted with each village group, enabling us to estimate the proportion of land use area in the village for eight main land use types, including cultivated land, unused land, residential area, forest, lowland floodplain, grazing land, woodland, and water. Ninety-five percent of the villages (97 out of 102) were located more than 5 kilometers apart, which ensures that villages can be considered to a large extent independent with respect to landscape effects on pest and natural enemy communities (Bianchi et al., 2006, 2008; Rusch et al., 2016; Thies et al., 2003).

2.3. Data analysis

Since the household survey recorded "reported" (or perceived) pest severity, as opposed to "observed" pest severity, it is important to consider the socio-economic factors that may influence respondents' perceptions, along with other important dimensions of production situations (i.e., landscape, agronomic and biophysical factors) (Table 1). Natural enemies and their pest suppression services were largely unknown to Nigerian farmers (Zhang et al., 2016). As information on the prevalence of natural enemies was not available from survey respondents, we did not model natural enemy presence directly, but instead incorporated their role in the system through two channels. First, the pest suppression ecosystem service of natural enemies was captured by the landscape factors with regard to land use types and presence of non-crop habitat. Second, the mortality effect of insecticide applications on natural enemies, which in turn may result in pest population resurgence or increase, was accounted for by incorporating the village-level extent of insecticide application among farmers.

The relationship between pest severity and chemical insecticide application is complex: (i) insecticide usage may increase with perceived pest severity, (ii) use of insecticides usually reduce pest levels as an immediate effect and farmers who use insecticides may tend to rationalize that insecticide use has decreased pest severity, and (iii) use of broad-spectrum insecticides will kill natural enemies, making the crop more susceptible to colonization by pests once the insecticide is no longer effective. In such reciprocal causality system, estimating the effect of insecticide use on pest severity with observational data is challenging. To address the second relationship, insecticide use should be included as an explanatory variable to explain reported pest severity. However, this is not desirable from an estimation perspective because it

Table 1
Summary statistics for variables used in the regression analysis (N = 805).

Variables	Type of variable	Mean	Std. Dev.	Min	Max
Reported pest severity (dependent variable $PestSeverity_{iv}$)	Censored continuous	2.17	0.62	1	3
Household-level management practices (A_{iv}):					
Grew maize	Binary	0.54	0.50	0	1
Grew rice	Binary	0.20	0.40	0	1
Grew yams	Binary	0.31	0.46	0	1
Grew cassava	Binary	0.45	0.50	0	1
Grew sorghum	Binary	0.32	0.47	0	1
Grew millet	Binary	0.16	0.37	0	1
Grew leafy vegetable	Binary	0.07	0.25	0	1
Irrigation	Binary	0.25	0.44	0	1
Improved varieties	Binary	0.63	0.48	0	1
Chemical fertilizer	Binary	0.80	0.4	0	1
Manure	Binary	0.38	0.5	0	1
Mixed cropping	Binary	0.52	0.5	0	1
Crop diversity (number of crop types)	Continuous	5.23	1.8	1	13
Household socio-economic characteristics (H_{iv}):					
Age of household head	Continuous	51.8	13.0	15	96
Female-headed household	Binary	0.07	0.2	0	1
Household size	Continuous	10.01	4.7	1	42
Farm size (hectare)	Continuous	4.04	8.1	0	110
Ethnicity: Hausa	Binary	0.33	0.47	0	1
Ethnicity: Nupe	Binary	0.09	0.29	0	1
Ethnicity: Ibo	Binary	0.11	0.32	0	1
Ethnicity: Yoruba	Binary	0.16	0.37	0	1
Ethnicity: Other	Binary	0.30	0.46	0	1
Village-level land use (L_v):					
Unused land (area%)	Continuous	15.73	20.18	0	90.9
Residential land (area%)	Continuous	9.69	11.01	0	57.0
Forest (area%)	Continuous	10.38	15.03	0	60.0
Floodplain (area%)	Continuous	8.59	8.53	0	47.4
Grazing land (area%)	Continuous	0.96	2.98	0	20.0
Woodland (area%)	Continuous	3.50	6.47	0	27.3
Water (area%)	Continuous	3.00	5.83	0	51.5
Cultivated (area%)	Continuous	26.41	23.61	0	100
Village characteristics (V_v):					
Percentage of farmers spraying (%)	Continuous	34.78	38.1	0	100
Distance of village to insecticide store (km)	Continuous	3.8	6.1	0	30
Percentage of households eating < 2 meals/day (%)	Continuous	18.79	28.2	0	99
Distance to all-weather road (km)	Continuous	5.62	12.9	0	100
Biophysical factors (B_{iv}):					
Altitude (meters above sea level)	Continuous	273.1	185.3	14	795
AEZ: Humid Forest	Binary	0.35	0.48	0	1
AEZ: Guinea Savannah	Binary	0.34	0.47	0	1
AEZ: Sudan Savannah	Binary	0.31	0.46	0	1

violates the assumption of independence of explanatory variables and the error term, referred to as an endogeneity problem in the econometrics literature (Wooldridge, 2013). In this case, the cause of the violation arises because of simultaneity, a loop of causality between the explanatory (household's insecticide use) and dependent (household's reported pest severity) variables of the model. To deal with this issue, we excluded household's insecticide use from the model of reported pest severity and included a village-level variable "the distance to the nearest insecticide store of the village" to capture insecticides access in the village, which is expected to affect the probabilities of individual households using insecticides. The simultaneity concern is mitigated because pest severity does not affect village-level access to insecticides, at least not in the short term. Lastly, to control for the third relationship (impact of insecticides on natural enemies), we included village-wide extent of insecticide application. Robustness checks were conducted to provide additional justification for the exclusion of household's insecticide use as an explanatory variable in the reported pest severity model (Appendix D).

Based on this conceptual framework, we constructed a multiple regression model to empirically identify the factors associated with reported pest severity:

$$PestSeverity_{iv} = \beta_0 + \beta_1 {}^*L_v + \beta_2 {}^*A_{iv} + \beta_3 {}^*H_{iv} + \beta_4 {}^*V_v + \beta_5 {}^*B_{iv} + \varepsilon_{iv} \quad (1)$$

where i and v index households and villages, respectively. $PestSeverity_{iv}$ is pest severity reported by household i in village v and is measured with a composite "pest severity index". L_v is a vector of village-level land use variables that proxy the ecological (landscape) factors; A_{iv} is a vector of household-level management variables that capture the agronomic factors; H_{iv} is a vector of household socio-economic characteristics; V_v is a vector of village characteristics; B_{iv} is a vector of biophysical factors including altitude (meters above sea level) recorded at the household level ($Altitude_{iv}$) and dummy variables for agro-ecological zones (Table 1). Lastly, ε_{iv} is a random error term.

The pest severity index, $PestSeverity_{iv}$, was computed by averaging reported pest severity levels of different pest groups for each household as $\frac{\sum_m^M \sum_n^N Pestseveritylevel_{nm}}{Totalnumberofpestgroupsreportedbythehousehold}$, where n and m index insect pest groups and crop types, respectively, for each household, $n \in (1,2)$ (as each household can report up to two insect pest groups per crop type) and $m \in (1,3)$ (as each household listed up to 3 crop types). The composite "pest severity index", ranging between 1 and 3, is thus an aggregate measurement of pest pressure perceived by households. Since pest severity index is a censored continuous variable (i.e., bounded between 1 and 3),[2] we estimated a Censored Least Absolute Deviations (CLAD) estimator, which corrects for censoring the dependent variable (Powell, 1984) and is robust against departures of errors from homoscedasticity and normality (Wilhelm, 2008). All regression analyses were conducted in STATA (StataCorp LP, 2013).

3. Results

3.1. Main field crops, pests and management practices

Thirty-six crops were reported in the survey, but some at low frequencies (Table E-1 in Appendix E). Maize (*Zea mays* L), cassava (*Manihot esculenta* Crantz), and sorghum (*Sorghum bicolor* L.) were the most common crops, which were cultivated by 54%, 45% and 32% of the households, respectively (Fig. 2). Other common crops were yam (*Dioscorea* spp.), rice (*Oryza sativa* L.), cowpea (*Vigna unguiculata* L.), millet (*Pennisetum glaucum* L.), groundnut (*Arachis hypogaea* L.), and egusi melon (*Colocynthis citrullus* L.). Maize and rice were grown in all three zones, while cassava, yam, and egusi melon were only reported in the Humid Forest and Guinea Savannah (Fig. 2). Sorghum, cowpea, millet and groundnut are crops of the drier areas, and were virtually absent in the Humid Forest.

A total of 54 pest insect groups were reported (Table E-2 in Appendix E). The most frequently reported pest insects include grasshoppers (*Caelifera* spp.), unspecified caterpillars (Lepidoptera: i.e. larvae of butterflies and moths), African armyworm (*Spodoptera exempta* Walker), aphids (*Aphidoidea* spp.), stemborers (larvae of specific Lepidoptera species that bore into plant stems), great yam beetle (*Heteroligus meles* Billb.), termites (*Isoptera* spp.), sorghum midge (*Contarinia sorghicola* Coq.), and pod borers (larvae of specific Lepidoptera species that bore into pods). While most insect groups were reported by households from all AEZs, some pest insect groups were

[2] Censoring refers to a condition in which the value of a measurement is not observable for part of the population (Wooldridge, 2002). Censored regression models developed in the field of econometrics may be used to handle censored data (e.g., Tobin, 1958; Schnedler, 2005).

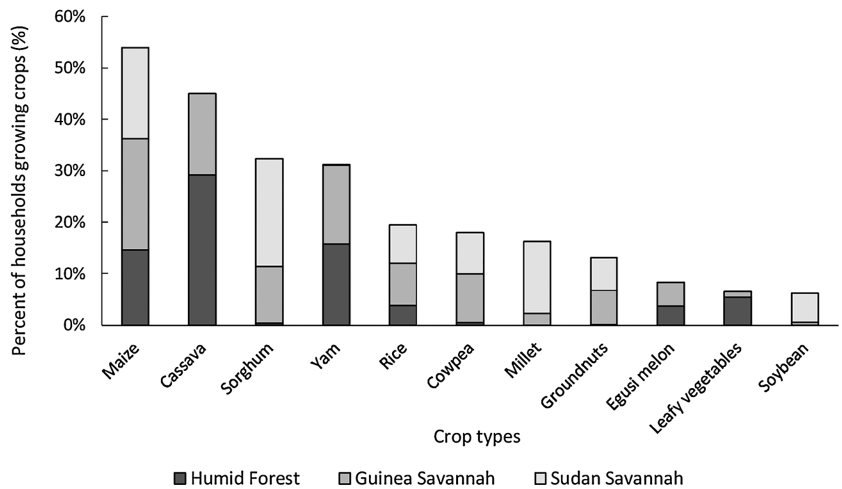

Fig. 2. Frequency distribution of main crops grown in three agro-ecological zones in Nigeria (see Fig. 1 for the location of the agro-ecological zones).

restricted to the AEZs where the host plants are grown (e.g. great yam beetle was only reported in the yam producing Guinea Savannah and Sudan Savannah).

Pest insect groups were associated with certain crops. Even when insect groups were aggregated into 8 major classes, crop-insect relationships remained apparent (Fig. 3). For instance, grasshoppers were often reported in cassava and to a lesser extent in maize, whereas Dipteran pests (e.g. African rice gall midge, *Orseolia oryzivora*) were important in rice and sorghum. Stem- and pod borers were often reported infesting maize and millet, while leaf feeding Coleoptera were mainly reported infesting yam.

Three quarters of all reported insect pest cases were considered as serious or moderate, of which nearly 40% being serious. Chemical insecticide use was the primary control method in 75% of the reported cases of pests, whereas cultural control methods (pest management based on the manipulation of crop systems, e.g., crop rotation, intercropping, and early planting; Agrios, 2005; Goodell, 2009) accounted for 8.7%. For the top three crops maize, cassava, and sorghum, about 70%, 57% and 78% of the households applied insecticides on pests affecting the respective crops. Insecticides were applied 2.3 ± 1.9 (mean ± sd), 2.0 ± 0.9, and 2.0 ± 1.0 times for each crop in the growing season, respectively. While insecticides were used to control a wide variety of pests, a relatively large proportion of households reported insecticide applications against leaf feeding Lepidoptera. The most important decision factors for choosing insecticide products were efficiency (51%) and price (18%). Seventy percent of households

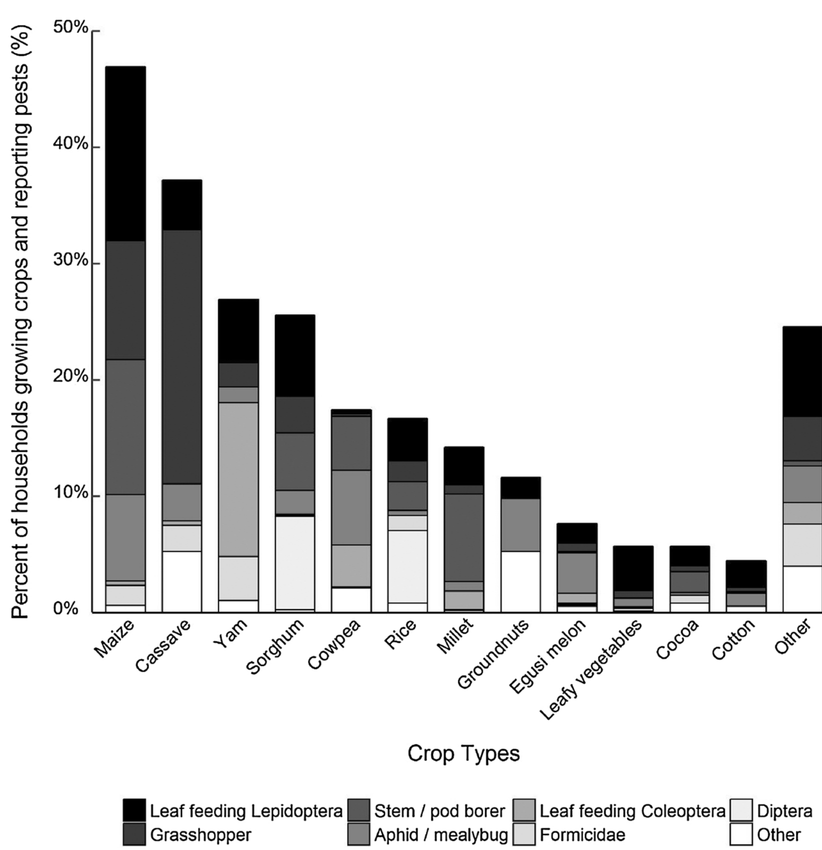

Fig. 3. Frequency distribution of crop-pest groups associations.

reported an increasing trend in insecticide prices over time. Nevertheless, almost half of the households reported an increase in use of chemical insecticides in the last 5 years. Almost 18% of households reported using application doses higher than the label recommended dose.

The far majority of the respondents considered chemical insecticides hazardous (96%), which they learned from own experience or from neighbors or friends (62%), extension agents or insecticide salespersons (20%), and product labels (13%). While the majority of the respondents took measures for personal safety (e.g., wearing protective clothing when spraying and washing hands after spraying), unsafe handling and disposal of empty containers and wash water was widespread. Among those who washed insecticide sprayers after application (90%), 16% washed by the river or lake, 21% dumped the wash water into a crop field, and 19% dumped it anywhere that was convenient. In addition, 37% of the households reported leaving the empty insecticide containers in the crop field, 16% left them anywhere that was convenient, and 14% burned the containers.

3.2. Factors associated with reported pest severity

Regression analysis indicated that the proportions of forest, unused land, and residential area in the village were significantly associated with lower reported pest severity by households, as compared to cultivated land, which was the reference land use type (Table 2). This implies that, converting any of these land uses to cultivation land use in the village may increase the average pest pressure experienced by individual households, holding everything else constant. The share of lowland floodplain, relative to cultivated land, was associated with higher pest severity reported by households.

In terms of management practices, the use of chemical fertilizers and manure was associated with lower pest severity as compared to households that didn't fertilize. Households that adopted mixed-cropping reported lower pest severity than those that didn't adopt this practice. Households that grew maize, yam, or cassava reported lower average pest severity as compared to those that didn't cultivate each respective crop, whereas growing rice or leafy vegetables was associated with higher reported pest severity. This implies that staple crop cultivation may be less prone to pest attack than vegetables. Moreover, the age of household head and female headship were negatively related to reported pest severity.

In terms of village-level characteristics, the percentage of farmers in the village that applied insecticides was negatively associated with pest severity perception, but its squared term had a positive association. The distance to the nearest chemical insecticide store or to an all-weather road was not significantly correlated with reported pest severity. With respect to the biophysical factors, altitude was positively related to reported pest severity.

Table 2
Parameter estimates, standard errors and significance levels for variables explaining reported pest severity. Reference variables are "Hausa" for ethnicities, "Cultivated land (area%)" for land use, and "Humid Forest" for AEZ.

Explanatory variables	Parameter	s.e.
Village-level land use:		
Unused land (area%)	−0.004***	0.001
Residential land (area%)	−0.006***	0.002
Forest (area%)	−0.003**	0.001
Floodplain (area%)	0.005**	0.002
Grazing land (area%)	−0.005	0.006
Woodland (area%)	−0.001	0.003
Water (area%)	−0.002	0.003
Household-level management practices:		
Irrigation	−0.076	0.046
Improved varieties	0.045	0.038
Chemical fertilizer	−0.121***	0.046
Manure	−0.144***	0.047
Mixed cropping	−0.090**	0.039
Crop diversity (crop count)	−0.004	0.010
Grew maize	−0.107***	0.038
Grew rice	0.094*	0.048
Grew yams	−0.172***	0.044
Grew cassava	−0.159***	0.054
Grew sorghum	−0.017	0.047
Grew millet	0.084	0.062
Grew leafy vegetables	0.259***	0.072
Household socioeconomiccharacteristics:		
Age of household head	−0.004***	0.001
Female-headed household	−0.140**	0.068
Household size	−0.005	0.004
Farm size (hectare)	−0.001	0.002
Ethnicity: Nupe	0.032	0.105
Ethnicity: Ibo	−0.165	0.120
Ethnicity: Yoruba	−0.131	0.106
Ethnicity: Other	−0.095	0.095
Village characteristics:		
Percentage of farmers spraying (%)	−0.006**	0.003
Percentage of farmers spraying squared	6.4e−05**	0.000
Distance of village to insecticide store (km)[a]	0.004	0.003
Percentage of households eating < 2 meals/day (%)	0.001	0.001
Distance to all weather road (km)	0.002	0.001
Biophysical factors:		
Altitude (meters above sea level)	0.0003*	0.000
AEZ: Guinea Savannah	0.102	0.069
AEZ: Sudan Savannah	−0.204	0.127
Constant	2.981***	0.146
Observations	805	
Pseudo R-squared	0.072	

*** $p < 0.01$.
** $p < 0.05$.
* $p < 0.1$.
[a] The distance is zero for those villages that have an insecticide store in the village.

4. Discussion

Reported pest severity was associated with a suite of landscape, agronomic, and socio-economic factors, highlighting the complexity underlying pest management decisions and the importance of farmers' production situations.

Reported pest severity was negatively associated with the proportion of forest and unused land, as compared to cultivated land that served as a reference. This finding is in line with the general pattern of a positive relationships between the proportion of non-crop habitat in the landscape, higher and more diverse natural enemy communities (not quantified in this study), and a tendency for better natural pest suppression (Bianchi et al., 2006; Chaplin-Kramer et al., 2011; Veres et al., 2013, but see Tscharntke et al., 2016 for counter examples). Our study indicates that the pest suppressive effects of a diverse landscape hold also in African smallholder agriculture settings, which is of particular importance for farmers who lack access to insecticides.

The proportion of residential area was negatively related to reported pest severity. There are two possible explanations for this finding. First, residential land in rural Africa often contains home gardens that have a high plant species diversity and a high structural vegetation complexity (e.g., Zhang et al., 2016). These home gardens may have supported natural enemy populations. Second, the area of residential land within a village domain may be positively associated with income levels and access to information. Wealthier and better-informed farmers may be more likely to use insecticides, resulting in lower pest severity. Furthermore, the proportion of lowland floodplain, relative to the proportion cultivated area, was positively correlated with reported pest severity. This may be explained by the expansion of the area of intensive vegetable farming on floodplains in Nigeria in recent years (Dam, 2012), which are associated with a high pest severity (Table 2).

In contrast to most ecological studies where land use information is collected via GIS analyses, we adopted a semi-quantitative approach by asking respondents about the major land uses in the village and their area allocations. Most landscape studies are based on ecological study designs, with usually a maximum number of landscapes in the order of 20, beyond which the workload for GIS mapping, survey, and travel time for taking measurements makes the workload insurmountable. While the survey-based land use assessment approach provides less detailed data than the GIS approach and has a drawback of potential reporting bias, its strength is that due to the reduced work load a higher number of landscape replicates may be obtained when combined with socioeconomic survey field work (102 villages in this study). This level of replication is unique for empirical studies that assess landscape effects on pest pressure. In addition, the survey-based approach may be a low-tech alternative to GIS mapping when a GIS analysis is not feasible, for instance in developing countries and regions dominated by smallholder farms (Zhou et al., 2014).

Reported pest severity was associated with crop management, which is in line with previous studies (e.g., Allinne et al., 2016; Avelino et al., 2006; Savary et al., 2017). The use of manure and chemical fertilizers was negatively associated with pest severity, possibly because the enhanced soil fertility and soil biota may allow plants to better compensate for herbivory (Rosenheim et al., 1997; Wilson et al., 2003). Manure application has earlier been associated with reduced pest densities (Alyokhin and Atlihan, 2005; Eigenbrode and Pimentel, 1988), while the effects of artificial nitrogen fertilizer on pest dynamics are mixed and may differ for sucking and chewing insect herbivores (Nicholls and Altieri, 2004). Reported pest severity was lower in mixed-cropping systems than in mono-cropping systems. Indeed, the pest suppression benefit of diverse cropping systems has been recognized for a long time (Andow, 1991; Root, 1973; Altieri, 2004; Thrupp, 2000; Tsafack et al., 2016). Our findings support the premise that diversified agroecosystems have a higher capacity to suppress pest (Altieri, 2004; Thrupp, 2000), and that cultural control methods offer complementary suppression without or with a reduced dependency on chemical insecticides.

Our data indicated that household characteristics were associated with pest severity perception, which has important implications for the development of policy tools and targeting strategies. We found that female-headed households reported lower pest severity, which corroborates the findings of Nkamleu and Adesina (2000) who found that female household headship was negatively correlated with insecticide use in Cameroon. More generally, men tend to use higher input levels than women, and that this input gap is responsible for observed productivity differences between men and women (Peterman et al., 2014). Our analysis offers a new perspective on the relationship between female headship and pest severity perception in Nigeria, which merits further investigation.

Households with older heads tended to report lower pest severity than households with younger heads. A possible explanation is that older farmers may have more farming experience and may be able to apply better pest management through alternative control methods. Furthermore, older farmers may perceive pest severity lower as they may be more aware of the potential of crops to tolerate or compensate for pest attack, and are therefore more likely to refrain from using insecticides. Evidence on the effect of farmer age on technology adoption is mixed in the literature. While some studies show that younger farmers are generally more likely to adopt new technologies (e.g., Alavalapati et al., 1995), others have argued that older farmers may have preferential access to new information or technologies or are more likely to invest in innovations because of greater accumulated personal capital (Nkamleu et al., 1998; Nkamleu and Adesina, 2000). In Cameroon, fertilizer use or insecticide use was not related to age of farmers (Nkamleu and Adesina, 2000). Our data from Nigeria suggest that using knowledge of more experienced farmers may help to reduce the reliance on insecticides.

The negative and positive coefficients for the percentage of farmers at the village level that applied insecticides and its squared term, respectively (Table 2), indicate a nonlinear relationship with low perceived pest severity at low levels of insecticide use and increasing perceived pest severity at higher pesticide use at the village level. One can conceive that as insecticide application becomes more widespread across local systems, the non-target mortality effects of insecticide use on natural enemies becomes an increasingly important driving factor in pest densities, resulting in higher reported pest severity, whereas at low pesticide use frequency with sufficient refuge for natural enemies, pest severity might still decrease with greater use. As compared to many emerging economies in Asia, the current rate of insecticide application in Nigeria is still moderate (Bell et al., 2016; Huang et al., 2010; Zhou et al., 2014), but great attention needs to be given to the possibility of secondary pest outbreaks as farmers continue to expand the use of broad-spectrum insecticides.

In this study, we used reported or perceived pest severity but did not measure actual pest levels in the field. The quantification of pest levels was not feasible given that the study comprised more than 800 households, representing a high diversity of crops and associated pest species, and a high temporal variation in pest densities requiring multiple assessments in the growing season. Even if the reported pest severities would be biased by personal attitudes and perceptions (beyond what we have controlled for in the model), they are still relevant for decision making because the reported or perceived pest severity informs decision making. Therefore, it could be argued that from a sociological and decision-making perspective, the perceived pest severity is more relevant than the actual pest severity. Evidently, further research on the relationship between actual and perceived pest severity is needed to obtain deeper insight in drivers of pesticide use by farmers.

5. Conclusions

In conclusion, our findings indicate that the presence of non-crop areas in the landscape and the diversification of agroecosystems may be a viable strategy for smallholder farmers to manage pests with limited reliance of chemical insecticides in Nigeria, but that actual pest management decisions could be influenced by a wide range of context-specific factors. Looking at the broader implications of the study, reducing yield loss to pests while reducing the reliance on chemical insecticides is a major challenge in Nigeria, but it is also an important component in achieving sustainable food security and development. Closing yield gaps via pest management requires addressing both the constraints around (i) the sustainable use of ecosystem services associated with biodiverse landscapes and agro-ecosystems that reduce the need for chemical insecticides, and (ii) access to selective and environmentally benign insecticide products, their informed use, and the affordability to farmers.

Acknowledgements

The research was carried out under the CGIAR Research Programs on Policies, Institutions and Markets (PIM) and Water, Land and Ecosystems (WLE) with support from CGIAR Fund Donors (http://www.cgiar.org/about-us/our-funders/). We thank Ephraim Nkonya, Hassan Ishaq Ibrahim, Mure Agbonlahor, and Hussaini Yusuf Ibrahim for contributing to the data collection, Adebayo A. Omoloye for providing inputs on field crop pests in Nigeria, and Samson K. Foli, Adebayo A. Omoloye, and James Ojo for preparing a field guide on insects to facilitate the farmer interviews. We are grateful for farmers who participated in our survey, the enumerators who carried out the interviews, and the extension agents for facilitating the field work. Figure 1 is used with permission from Zhang, W., E. Kato, P. Bhandary, E. Nkonya, H.I. Ibrahim, M. Agbonlahor, H.Y. Ibrahim, and C. Cox, “Awareness and Perceptions of Ecosystem Services in Relation to Land Use Types: Evidence from Rural Communities in Nigeria” *Ecosystem Services* 22(A): 150-160. Elsevier, copyright 2016.

Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at https://doi.org/10.1016/j.agee.2018.03.004.

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