

ARTICLE

Regulating agricultural intensification: Lessons from West Africa's rapidly growing pesticide markets

Steven Haggblade¹ | Amadou Diarra² | Abdramane Traoré³

¹Professor of International Development, retired. Department of Agricultural, Food and Resource Economics, Michigan State University, USA

²Agronomist and consultant to Michigan State University, Former Permanent Secretary for the Comité Sahélien des Pesticides (CSP), Bamako, Mali

³Senior Advisor for Research and Outreach, Projet de Recherche sur les Politiques de Sécurité Alimentaire au Mali (PRePoSAM), Michigan State University, Bamako, Mali

Correspondence

Steven Haggblade

Email: blade@msu.edu

Funding information

Funding for this work has come from three major sources:

- (1) West Africa Regional Bureau of the US Agency for International Development (USAID) through Food Security Innovation Lab contract AID-OAA-L-13-00001.
- (2) USAID/Mali through Cooperative Agreement AID-688-A-16-00001.
- (3) U.S. Department of Agriculture's Foreign Agricultural Service (FAS) Agreement No. FX18TA-10960R023 with Michigan State University.

Abstract

Motivation: Imports of pesticides, especially herbicides, almost tripled in value across West Africa between 2005 and 2015. This remarkable increase has been driven by falling prices of generic pesticides, rising costs of farm labour for weeding, rising demand for farm produce, and the recent invasion of an exotic pest from the Americas, the fall armyworm (*Spodoptera frugiperda*).

Despite rapid growth in pesticide markets, policy enforcement has not kept pace. As a result, fraudulent pesticides—often underdosed—now account for roughly one-third of pesticides sold in the region. Fraud on this scale compromises agricultural growth, human health and environmental safety.

Purpose: This article aims to assess the consequences of rapidly growing pesticide markets for farmers, traders and policy-makers.

Approach and methods: Seven national studies of pesticide markets and policy implementation—in Côte d'Ivoire, Gambia, Ghana, Guinea, Mali, Nigeria and Senegal—provide empirical evidence for this article. Following reviews of existing documents and statistics, each study involved structured interviews with regulators, policy-makers, traders and farmers. Multiple feedback sessions with key regional stakeholder groups vetted core findings.

Findings: The investigations reveal rapid changes in the structure and performance of pesticide supply chains, including a major proliferation of generic brands and unlicensed traders, high levels of fraud, and wide variability in pesticide quality. In response, four broad regulatory models are emerging across Africa: (1) purely national testing, registration and monitoring; (2) harmonized regional protocols for testing, with national registration and monitoring; (3) regional testing and registration with national monitoring; and (4) regional testing, registration and monitoring. Purely national models are most common, but they prove costly for Africa's many small countries.

In all models, weaknesses in post-registration monitoring and enforcement mean that risks to human health and the environment go largely unmonitored.

Policy implications: The findings suggest several practical avenues for improving agricultural input quality and environmental safety. In the short term, stakeholder coalitions of responsible traders, farmer groups and regulators can campaign for authentic products, researchers need to step up

environmental monitoring of pesticide use and impacts, and pest control specialists appear poised to continue encouraging integrated pest management to economize on use of chemicals. In the medium term, moves to regional harmonization and co-operation reduce opportunities for smuggling and enable regional pooling of scarce technical personnel, while policymakers seek feasible ways of expanding resources for registration and monitoring systems commensurate with the rapid increases in pesticide use. In political economy terms, current pest invasions open a window of opportunity potentially enabling necessary structural reform of pesticide policies and regulatory systems.

KEYWORDS

Africa, agriculture, fraud, pesticides, regulation

1 | INTRODUCTION

Environmental and demographic pressures on arable land make agricultural intensification necessary to feed Africa's growing population. Home to the world's highest fertility rate as well as its youngest and most rapidly growing population, Africa faces increasing pressure to feed its rapidly expanding urban population (IFAD, 2016; AGRA, 2020). Corresponding pressure on arable land reinforces farmer incentives to intensify production in order to keep pace with growing urban food demand (Jayne et al., 2014; Tschirley et al., 2015).

In response, pesticide use has expanded rapidly in West Africa over the past 15 years (Figure 1), led primarily by growing application of herbicides (Table 1).¹ The global emergence of low-cost generic pesticides has fuelled economic incentives for onfarm adoption, as patent protection for major active ingredients has expired (DM Intelligence, 2019; Haggblade, Minton et al., 2017). The most recent example occurred late in the year 2000 when international patent protection for the world's most widely sold herbicide, glyphosate, expired. Since then, global prices for generic brands of this active ingredient have fallen by over 50% (Benbrook, 2016). Compounding farmer incentives to adopt herbicides, the recent wave of low-cost generic herbicides arrived in West Africa at the same time as growing urbanization increased nonfarm employment opportunities, thus exacerbating rural labour shortages. The resulting combination of rapidly falling generic herbicide prices and rising rural wage rates has made herbicide use increasingly economically attractive for African farmers (Tamru et al., 2017). In southern Mali, farmers report that they can now manage weeds using herbicides at 50% of the cost of hand weeding (Haggblade, Smale et al., 2017).

Regulatory capacity, however, has not kept pace with the rapid growth in pesticide sales. As a result, fraudulent pesticides of dubious quality now account for roughly one-third of pesticides sold in West Africa (Haggblade, Diarra et al., 2019; MIR Plus, 2012). Recent laboratory testing of glyphosate, the most commonly sold pesticide active ingredient in the region, suggests that fraudulent products contain roughly 10% less active ingredient than registered products as well as more variable dosages (Haggblade, Diarra et al., 2019). Similar quality problems plague other farm inputs such as fertilizer and seeds (Ashour et al., 2018; Bold et al., 2017).

¹The term "pesticide" refers to a broad set of phytosanitary products used by farmers to combat agricultural pests: herbicides to combat weeds, insecticides to combat insect pests, nematicides to combat nematodes, fungicides to combat fungal pests and rodenticides to combat rodent predation of major food crops.

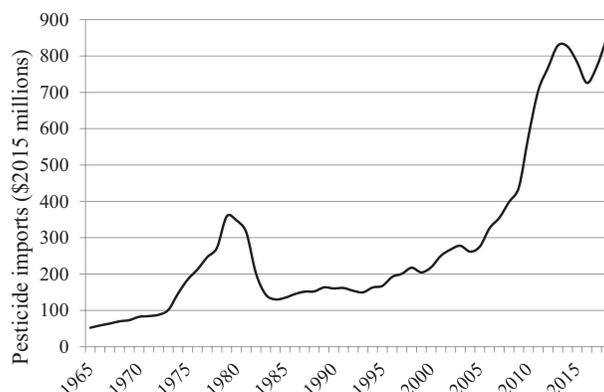


FIGURE 1 Trends in pesticide imports into West Africa (millions of US dollars, 3-year centred moving averages, deflated to constant 2015 dollars).

Source: FAOSTAT (n.d.)

TABLE 1 Composition of pesticide imports into West Africa, 2015*

Pesticide products	Imports	
	USD billions	Percent
Herbicides	438	55%
Insecticides	220	27%
Others**	140	18%
Total	798	100%

*Average, 2014 to 2016; **Fungicides, growth regulators, rodenticides, nematicides.

Source: FAOSTAT (2020).

Input quality problems on such a broad scale raise multiple problems. Agriculturally, frustrated farmers routinely complain about the bewildering variety of generic brands on sale and the uneven results they achieve (Ashour et al., 2018; Assima, Ketia et al., 2017). Without quality assurance, farmers risk losing faith in the purchased inputs necessary to raise productivity and feed growing cities. Environmentally, variable and often underdosed pesticide applications favour the emergence of agricultural pest resistance—in the same way that failure to complete a course of antibiotics leads to antibiotic resistance in human medicine.² Thus, the short-term risk to farm productivity paves the way for potentially more serious long-term environmental and food security dangers should existing active ingredients be rendered ineffective.

Looking forward, the recent arrival of an exotic plant-eating pest from the Americas appears likely to trigger a new wave of accelerated pesticide use across Africa, this time with market growth concentrated in more highly toxic insecticides. The accidental introduction of *Spodoptera frugiperda*—fall armyworm (FAW)—into Africa's major cereal-producing regions, beginning in 2016, has led farmers to ramp up their use of chemical insecticides (FAO, 2019a, 2019b; Murray et al., 2019). Although FAW has also motivated researchers to ramp up testing of biological control options and integrated

²Several common onfarm practices—such as inappropriate active ingredients, poorly timed application and frequent over use—further contribute to pest resistance.

pest management practices (IPM), the default short-term response by farmers and many pest control agencies has been to increase application of chemical insecticides (Bateman et al., 2018; FAO, 2018; Jepson et al., 2020). The resulting increases in pesticide use and toxicity are placing growing stress on pesticide regulatory systems.

This article aims to distil practical lessons emerging from the first wave of herbicide-induced pesticide growth in West Africa in order to help farmers, input suppliers and policy-makers ensure farm productivity growth and environmental safety in the coming decades. Specifically, the article tackles three related objectives. First, it documents the rapid growth in West African pesticides markets and the ensuing consequences for supply chains, farmers and regulators. Second, the article summarizes the varied policy responses across the region as well as the consequences of generally weak post-registration enforcement under all of the commonly applied regulatory models. Finally, the article identifies key policy lessons emerging from this initial wave of pesticide growth in the hope that these lessons will assist stakeholders to prepare for the anticipated second wave of more highly toxic insecticides. These lessons arrive at a potentially propitious time, since policy reform often proves most feasible at moments when external shocks open “policy windows” that empower stakeholders and motivate policy-makers to modify existing policy stances (Kingdon, 1995; Resnick et al., 2018). Africa’s emerging fall armyworm invasion represents a short-term crisis that could open such a “policy window” by serving to mobilize the political will necessary to institute needed regulatory reforms in Africa’s increasingly overstretched pesticide regulatory systems.

The article is organized as follows. Section 2 provides a review of data, sources and methods. Section 3 summarizes evidence assembled about the causes of West Africa’s rapidly growing pesticide markets and consequences for farmers, traders and policy-makers. Section 4 reviews the region’s diverse policy responses and summarizes the three major regulatory models currently in operation. Finally, Section 5 summarizes key policy lessons emerging from the experiences of West Africa’s under-resourced regulatory systems confronting explosive agricultural input market growth. In doing so, the article identifies a series of practical steps that, taken now, can improve agricultural input quality and farmer confidence in the input supply systems required to increase agricultural productivity in coming decades.

2 | DATA AND METHODS

2.1 | Field studies

This article summarizes the results of seven national studies of pesticide policy implementation in West Africa as well as follow-up field surveys and laboratory research. The countries selected for in-depth review offer a contrast between the Sahelian countries³ that together introduced harmonized regional pesticide regulations in 1992 and the coastal countries that attempted, several decades later, to emulate the Sahelian model among the humid West African coastal countries, running from Guinea to Nigeria. The study team selected countries purposefully to represent a range of market sizes and regulatory experiences (Table 2). The countries examined include three Sahelian countries (Mali, Gambia and Senegal) that regulate pesticides jointly through the Comité Sahélien des Pesticides

³Nine Sahelian countries banded together in 1973 to form the Comité Permanent Inter-Etats de Lutte contre la Sécheresse dans le Sahel (CILSS) in order to co-ordinate regional responses to a series of severe regional droughts. The nine founding members of CILSS span a semi-arid expanse of West Africa running from Cape Verde to Burkina Faso, Chad, Gambia, Guinea Bissau, Mali, Mauritania, Niger, and Senegal.

TABLE 2 Countries selected for regional pesticide case study*

Market size (annual pesticide imports)	Sahelian CSP Countries	Coastal ECOWAS Countries
Large (over USD 100 million)		Côte d'Ivoire* Ghana* Nigeria**
Medium (USD 10 to USD 99 million)	Burkina Faso Mali* Senegal*	Guinea*
Small (USD 9 million or less)	Cape Verde Chad Gambia* Guinea Bissau Niger Mauritania	Benin Liberia Sierra Leone Togo

*Full case study countries; **Rapid appraisal only.

(CSP) as well as four coastal countries (Côte d'Ivoire, Ghana, Guinea and Nigeria) that regulate pesticides individually, though they have agreed, in principle, to establish a parallel sub-regional regulator for the humid coastal zone under auspices of the regional economic community ECOWAS.⁴

Each country study began by summarizing available empirical and descriptive evidence on pesticide markets, regulatory frameworks and key private and public sector actors affecting market growth and regulatory controls. Then, using a standard research protocol, each country team spent several weeks conducting formal interviews with national regulators and key private sector importers, distributors, retailers and farmers. Following their field visits, the country teams spent an additional month or more compiling and analysing available primary and secondary data and summarizing the qualitative views expressed by private traders, farmers and regulators. Given widespread evidence of fraudulent pesticide products circulating in West African markets, the research team also reviewed available empirical studies evaluating the level and composition of fraudulent pesticides on sale, active ingredient dosages in registered and fraudulent products, and assessments of pesticide risks to environmental and human health. In early 2017, the teams circulated full drafts to key informants in each country for review and comment prior to completion. The full research protocol, interview guides and list of persons interviewed are available in the final country reports, all of which are available online (see Diallo & Tasie, 2017; Diarra & Diallo, 2017; Diarra & Tasie, 2017; Haggblade et al., 2017; and Traoré & Haggblade, 2017a, 2017b). The data reported below rely primarily on non-published government regulatory information assembled by our research teams.

2.2 | Stakeholder outreach

To vet these findings, our research team conducted a series of five formal outreach events to present results from this emerging body of evidence to national and regional regulators as well as key private sector stakeholders. In November 2017 and again in May 2018, our lead researchers presented

⁴Founded in 1975, the Economic Community of West African States (ECOWAS) has 15 member states: Benin, Burkina Faso, Cape Verde, Côte d'Ivoire, Ghana, Guinea, Guinea Bissau, Gambia, Liberia, Mali, Niger, Nigeria, Senegal, Sierra Leone, and Togo. ECOWAS aims to promote economic integration as well as a West African free-trade zone.

key findings to the biannual meetings of regional regulators convened by the CSP in Bamako, Mali. Roughly 50 regulators, scientists and supporting agricultural sector stakeholders from 17 West African countries attended each of the CSP meetings. Participants provided feedback to the research team during the plenary presentation sessions and throughout the course of these one-week technical meetings.

Two additional regional workshops focused on the private sector. Because fraudulent pesticides divert market share from authorized suppliers, who duly comply with all regulatory testing and quality control requirements, the private sector has taken a keen interest in our ongoing empirical research on pesticide markets, regulatory systems, fraud levels and product quality. In April and August 2019, CropLife International, the global trade association representing the interests of the world's major agro-chemical companies and their regional distributors and associates, convened regional meetings in Africa with their major distributors as well as regional and national regulators. The April 2019 regional meeting, in Dakar, involved roughly 80 private sector and public sector representatives from 17 West African countries, while the August 2019 meeting in Nairobi involved a similar mix of roughly 100 pesticide suppliers and regulators from 14 countries in Eastern and Southern Africa. As with the regulator-convened conferences run by the CSP, participants from the private sector convenings provided valuable reactions that have helped to inform our understanding of the empirical findings presented below.

The fifth major vetting of this work took place at the request of the US Department of Justice (DOJ), which convened a workshop focusing on problems associated with fraudulent pesticides and pharmaceuticals in Africa. Held in Dakar in June 2019, the DOJ conference included pesticide regulators, customs officials, police and prosecutors from all of Francophone Africa, some 90 participants in all.

As a result of these interactions, the findings reported below have benefitted from extensive vetting by the key private and public sector stakeholders currently grappling with the unprecedented recent growth in African pesticide markets. The exposition below highlights the most important and broadly generalizable findings identified during these multiple stakeholder consultations.

3 | CAUSES AND CONSEQUENCES OF GROWING PESTICIDE MARKETS IN WEST AFRICA

3.1 | Pesticide market overview

Growth in West Africa's pesticide markets has accelerated rapidly, particularly since 2005 (Figure 1). Between 2005 and 2015, total pesticide imports into the region roughly tripled, with particularly rapid growth in the three largest agricultural markets—Côte d'Ivoire, Ghana and Nigeria (Table 3). In part, the more rapid growth in the large coastal markets results from bulk imports of active ingredients which traders subsequently trans-ship for sale in the smaller landlocked countries of the interior.

Disaggregating by category reveals that herbicides currently dominate West African pesticide markets, accounting for over 50% of total pesticide sales (Table 1). Herbicides substitute primarily for hand weeding labour, which has historically dominated farmers' weed control efforts. Field interviews with suppliers and regulators across the region consistently singled out the herbicide glyphosate as the most commonly sold pesticide in West Africa. Empirical data from Mali and Côte d'Ivoire confirm that glyphosate accounts for 38% and 51%, respectively, of total pesticide volumes sold (Haggblade, Keita et al., 2019; Traoré & Haggblade, 2017a). In second position regionally, insecticides account for a further 27% of pesticides used (Table 1). Fungicides, nematicides and other pest control products account for the remaining 18% of pesticides applied by West African farmers.

TABLE 3 Country-level trends in annual pesticide imports into West Africa (USD millions, 3-year centred averages, deflated to constant 2015 dollars)

	1995	2005	2015
Large markets			
Nigeria	21	59	323
Ghana	25	89	217
Côte d'Ivoire	31	41	133
Medium-sized markets			
Mali	21	28	37
Burkina Faso	10	28	24
Senegal	12	13	15
Guinea	3	4	11
Small markets*	43	14	40
West Africa total	168	275	798

*Benin, Cape Verde, Chad, Gambia, Guinea Bissau, Liberia, Mauritania, Niger, Sierra Leone and Togo.

Sources: FAOSTAT (2020).

3.2 | Causes of rapid market growth

3.2.1 | First wave, 2005 to 2015

Pesticide use grew rapidly across West Africa over the decade running from 2005 to 2015 (Figure 1), driven primarily by rapid increases in farmer uptake of herbicides. Several broad forces propelled this rapid ascent.

Expiring patent protection for major pesticide active ingredients has triggered the emergence of cheap generic competitors over the past several decades. In the face of growing costs of regulatory approval and diminishing gains from existing chemistry, the world's major agro-chemical research and development (R&D) firms have patented progressively fewer pesticide AIs in every decade since the 1990s (Duke, 2012; Fuglie et al., 2011; Hagglblade, Minten, et al., 2017). As a result, generic brands now account for about 60% of all pesticide sales globally (DataM Intelligence, 2019).

Most of the generic pesticides currently imported into Africa come from Asian suppliers, particularly in China and India. Profiting from low labour costs, large domestic markets and resulting economies of scale, Chinese and Indian suppliers achieve cost reductions that translate into a significant competitive edge in international markets. Huang et al. (2017) have described how Chinese suppliers rapidly scaled up production of herbicides in the early 2000s. By 2015, exports absorbed over 40% of China's total herbicide production. Our field interviews across West Africa point to the surge in glyphosate imports from China as the primary accelerator driving the inflexion point in West African herbicide imports around 2005 (Figure 1).

Pesticide prices have fallen—in Africa as well as globally—as a result of the growing availability of inexpensive generics. Since the year 2000, for example, glyphosate prices have fallen by over 50% worldwide (Benbrook, 2016).

Rising farm labour costs have fuelled further interest in herbicides. Over the past several decades, rapid urbanization has increasingly pulled rural labour off the farm and into West Africa's growing cities and towns (Hollinger & Staatz, 2015). Labour demand in gold mining has similarly enticed large numbers of young men out of rural farming communities to regional gold fields running from

Guinea to Ghana (Traoré & Haggblade, 2017). Agricultural input traders and regulators throughout the region emphasize the resulting impact of growing rural labour shortages on herbicide demand, even among small farmers who use them on staples as well as cash crops. Findings from Ethiopia (Tamru et al., 2017), Mali (Haggblade, Smale et al., 2017) and Uganda (Ashour et al., 2018) suggest that the combined effect of rising rural wage rates and falling herbicide costs together make herbicides an increasingly cost-effective option for controlling weeds in many African settings.

3.2.2 | Second wave, 2016 onwards

Just as West Africa's first wave of herbicide-induced pesticide growth began to crest, around 2015, a second wave of interest in pesticides began to form, this one fuelled by insecticides. In 2016, African plant protection services first reported the arrival of a voracious crop-eating insect pest from South America. The FAW first arrived in coastal West Africa—in Benin, Nigeria and Togo. From there, it spread rapidly across all regions of sub-Saharan Africa, to over 40 countries (FAO, 2019a). FAW caterpillars feed on the foliage, seeds and other vegetative structures of its host plants, leading to variable but substantial aggregate crop losses. In 2018, the FAO estimates that FAW destroyed 18 million tons of maize worth about USD 4.6 billion (FAO, 2019b). Though it prefers maize, the FAW feeds on a wide array of cereal crops, as well as cowpeas, groundnuts, vegetable crops, sugar cane and cotton.

Initial responses by farmers, and the plant protection agencies that support them, have centred around emergency application of highly toxic chemical insecticides (Bateman et al., 2018). Recent field assessments in Malawi, for example, have found farmers directly sprinkling undiluted organophosphates (profenofos) and pyrethroids (cypermethrin) onto affected plant leaves, without any protective gear (Murray et al., 2019).

Researchers and plant protection agencies have quickly recognized the potential danger to human health and the environment in the wake of widespread, reflexive recourse to highly toxic synthetic insecticides. Entomologists and allied agricultural researchers are, therefore, actively exploring alternatives to chemical pesticides—including biological controls with natural predators, biopesticides, natural pathogens, a variety of improved agronomic and IPM practices (Bateman et al., 2018; FAO, 2018; Prasanna et al., 2018).

Regulators have also reacted to the growing FAW threat. In June 2018, the European Union introduced emergency controls on agricultural imports from Africa to prevent the spread of FAW to Europe (M'Élla, 2019). African regulators have collectively engaged with private sector R&D firms, agricultural researchers and plant protection agencies through a series of continental consultative meetings. Following the lead of Sahelian West Africa, sub-regional groupings in coastal West Africa, and in Central, Southern and Eastern Africa have begun to fast-track the adoption of harmonized testing protocols and accelerated review processes for biological pesticides (EAC, 2019). For the first time in many decades, key government policy-makers have become aware of the growing strain on pesticide regulatory agencies as a result of the unfolding FAW invasion and its consequent threats to agricultural production, food security and human safety.

3.3 | Consequences of rapid market growth

New traders have entered West Africa's growing pesticide markets, attracted by increasing volumes and rapid turnover. In Côte d'Ivoire, the number of registered pesticide importers has increased five-fold, from 12 in the year 2000 to 67 in 2016. The number of registered pesticide retailers and applicators has increased even faster (Table 4). Even in smaller countries, growing pesticide markets have

TABLE 4 Trends in the number of registered pesticide traders and applicators

	2000	2016	Annual growth rate*
Côte d'Ivoire			
Importers	12	67	11%
Retailers	113	779	13%
Applicators	44	396	15%
Guinea			
Importers	2	21	16%

*Computed as the compound annual rate of growth between 2000 and 2016.

Source: Registration records supplied by Côte d'Ivoire's Direction de la Protection des Végétaux et du Contrôle de la Qualité (DPVCQ) and Guinea's Direction de la Protection des Végétaux (DPV).

attracted new traders. Since the year 2000, the number of registered pesticide importers in Guinea increased tenfold, from two to over 20 (Table 4).

Unregistered pesticide traders have entered the market as well. In Côte d'Ivoire, market participants estimate that about seven out of 10 pesticide retailers in Abidjan are registered, while in interior markets only two out of 10 are registered (Traoré & Haggblade, 2017b). Many of the unregistered traders operate seasonally, travelling by motorbike, bus or taxi to sell at weekly markets. In Mali, market watchers estimate that seasonal and itinerant traders may increase the number of pesticide retailers by as much as a factor of 10 in rural markets during the peak agricultural season (Haggblade, Diallo et al., 2017). Agricultural market visits reveal a broad spectrum of pesticide retailers—including general retailers, hardware stores, itinerant merchants and even bicycle- and shoe-repair shops. These conditions have amplified a proliferation of unlicensed pesticide traders that initially emerged across Africa following market liberalization and the closure of many parastatal input supply systems beginning in the 1990s (Williamson, 2003).

The number of pesticide brands on sale has increased nearly as rapidly as trader numbers. Time-series registration data, obtained by our research teams from regulators in the case study countries, indicate that the number of new pesticide products authorized for sale has grown at over 10% per year over the past decade (Table 5).

Registered generic formulations have driven the proliferation of pesticide products available for purchase. For the top-selling active ingredient, glyphosate, pesticide suppliers in the Sahelian countries had registered a total of 39 different generic products for sale as of December 2016, while Ghana had registered 70 and Côte d'Ivoire had approved 147 different generic glyphosate products for sale⁵ (Diarra & Haggblade, 2017). Registered generic brands have emerged for other major pesticide active ingredients as well. A recent market survey in Mali identified 10 or more different brands of herbicides for each of the following popular active ingredients: nicosulfuron, pendimethalin, haloxyfop-R-methyl, prometryn and 2,4-Dichlorophenoxyacetic acid (2,4-D). Similarly, insecticides containing lambda-cyhalothrin, acetamiprid and cypermethrin are all available under 10 or more different brand names (Haggblade, Keita et al., 2019). No wonder farmers complain of the difficulty of deciding which brands to purchase (Assima, Keita et al., 2017).

⁵In the face of this rampant brand proliferation, regulators in Côte d'Ivoire suspended all applications for new glyphosate brands beginning in December 2016.

TABLE 5 Growth in the number of pesticides products with valid registration numbers as of December 31 each year

Regulator pesticide products	Number of products registered			Annual growth rate ^{***}
	1995	2005	2015	
Comité Sahélien des Pesticides (CSP)				
Herbicides	2	38	144	15%
Insecticides	17	88	172	8%
Others	0	1	16	17%
All pesticides	19	127	332	11%
Ghana [*]				
Herbicides		36	212	10%
Insecticides		49	205	9%
Others		24	91	10%
All pesticides		109	508	10%
Guinea ^{**}				
Herbicides		10	94	17%
Insecticides		20	54	7%
Fungicides		2	10	12%
Others		4	4	0%
Total pesticides		36	162	11%

*Ghana data refer to 2006 and 2015; **Guinea data refer to 2001 and 2015; ***Computed as the compound annual rate of growth between the initial and ending years.

Source: Registration records supplied by the Comité Sahélien des Pesticides (CSP), Ghana's Environmental Protection Agency (EPA) and Guinea's Direction de la Protection des Végétaux (DPV).

Generic house-brand pesticides now appear routinely in West Africa. Even in a small country like Guinea, the firm Sako and Sons has registered a house brand of glyphosate called GlyphoSako, while Dynamique Agribusiness Enterprises has commissioned their own house brand, GlyphoDynamique, and the agribusiness firm EKAP Guinea has registered a house brand of glyphosate called GlyphoKap (Traoré & Haggblade, 2017b). In capital cities as well as small market towns in the interior, local traders importing a container load of pesticides can commission their own vanity pesticide brand already bottled, packaged and labelled with whatever logo the importer requires.

As a result, the structure of pesticide supply chains serving African markets has changed. A growing cohort of small and medium-sized Africa-based importers increasingly competes with the half dozen traditionally dominant international agro-chemical firms⁶ to source generic pesticides directly from China and India for import into African markets. In some cases, entrepreneurial employees working for the Big Six agro-chemical firms in Africa have quit to start their own, rival pesticide import businesses. In other instances, traders who previously served as local distributors for the big international firms have begun to source their own generic house brands directly from Asia. Large international agricultural commodity traders have, likewise, entered the pesticide business. Following

⁶The original Bix Six international pesticide research and development companies were BASF, Bayer, Dow, Dupont, Monsanto and Syngenta. Following a series of recent mergers and buyouts—Dow and Dupont, Bayer and Monsanto, China National Chemical Corporation and Syngenta—that number has shrunk to three.

local regulatory approval, they procure house-brand generic pesticides on a large scale from Asian suppliers and then deliver them to Africa for distribution through their import networks. To service this growing demand, a cluster of Asian manufacturers has emerged to produce generic, house-brand pesticide formulations on special order for individual African importers.

In prior decades, the large international agro-chemical companies managed tightly controlled pesticide supply chains through which they delivered their European-manufactured trademark brands to authorized local distributors in West Africa. Their authorized distributors, in turn, managed a network of local retailers whom they vetted, selected, trained and supported technically.

Over the past decade and a half, these tight controls—from manufacturer to importer to retailer—have been diluted by the flood of small and medium-sized importers peddling house-brand generic pesticides. The smaller firms, often general importers with little technical background in agricultural chemicals, frequently lack the expertise required to verify the quality of the products they receive from their Asian suppliers. Nor do they have the technical capacity to establish, monitor and backstop a distributor network. Instead, they sell their generic pesticides through a shifting and generally unmanaged network of intermediaries that ultimately sell to farmers.

The crowd of new entrants importing and retailing pesticides has led to a generally diminishing level of technical expertise and quality control throughout the distribution system. In Gambia, for example, analysis of 128 pesticide products on sale in local markets revealed that only 10% were properly labelled in original containers; fully 90% had been repackaged and were on sale in unlabelled bags and bottles. Among the unlabelled 90%, 28% contained banned substances, primarily highly toxic insecticides (Murphy et al., 2012).

Fraudulent⁷ pesticides—including both unregistered products and counterfeits—circulate freely within this newly fragmented distribution system, particularly in locations where regulatory enforcement remains lax. Efforts to quantify fraudulent pesticide market shares confront significant measurement difficulties, including seasonal and spatial variations in pesticide product composition as well as obvious trader reluctance to discuss fraud openly. The smattering of available empirical evidence, coupled with market visits in many diverse African settings, nonetheless clearly indicate that levels of fraudulent pesticide sales vary widely, across countries, across locations within a given country and between formal and informal retailers (MIR Plus, 2012; Ashour et al., 2018; Rodenburg, 2019; Haggblade, Keita et al., 2019). A recent empirical study commissioned by West African regional authorities provides a baseline estimate of the scale of fraudulent pesticide sales in the eight largest West African pesticide markets (MIR Plus, 2012). Taking a market-weighted average of their country-level estimates suggests that fraudulent pesticides in West Africa account for roughly 34% of total pesticide sales, 27% of them unregistered generics and 7% counterfeits (MirPlus, 2012). A 2019 survey in Mali finds a similar 26% share of unregistered generic pesticides in total sales (Haggblade, Keita et al., 2019).

Not surprisingly, given this level of fraud, farmers routinely complained to our field investigators about high variability in pesticide quality and the difficulties growers face in selecting from among the many different generic brands on sale. Recent laboratory testing suggests they have good reason to worry. Testing of glyphosate samples procured from four major agricultural markets across Mali indicates that, on average, fraudulent generic brands of glyphosate contain 8%–10% less active ingredient

⁷Fraudulent products include both counterfeits and unregistered generics. Counterfeiters strive to pass off their products as originals by using packaging nearly identical to well-established registered brands. In contrast, suppliers of unregistered generics introduce new brand names and packaging, but they circumvent the normal regulatory approval process in order to avoid costs associated with regulatory testing and registration requirements.

TABLE 6 Glyphosate dosage, by registration status

CSP registration status	Laboratory dosage / stated dosage			
	Average	Distribution		
		<75%	75-89%	90-110%
Unregistered	0.82	38	30	32
Registered	0.91	4	32	64
Total	0.87	18	32	50

Source: Haggblade, Diarra et al., 2019.

than brands duly registered with the relevant regulatory authorities (Haggblade, Diarra et al., 2019). In addition, active ingredient levels in fraudulent products vary more widely than dosages in registered brands. Fully 38% of the unregistered glyphosate products tested from Mali contained dosages less than 75% of the manufacturers stated value (Table 6). These findings suggest that *registered* generic glyphosate products offer generally good quality in terms of active ingredient dosages. Problems of underdosage and high variability lie primarily with *unregistered* generics (Table 6). Farm-level evidence confirms these quality differences, finding that application of registered herbicides reduces hand weeding labour significantly more than unregistered products do (Assima, Haggblade, & Smale, 2017). In East Africa, laboratory analysis of commercial glyphosate samples from Uganda similarly found that one-third of products tested contained below 75% of the stated concentration levels of active ingredient (Ashour et al., 2018).

Environmentally, these variable and often underdosed pesticide applications favour the emergence of pest resistance (Chouaïbou et al., 2016). Pest resistance, in turn, renders even good-quality brands of properly dosed pesticides ineffective. As with antibiotic resistance in human medicine, the emergence of pest resistance in agriculture risks rendering ineffective the pesticide active ingredients that farmers rely on most. Several common farmer management practices compound these environmental risks. Frequent application of inappropriate products (such as cotton pesticides on horticultural products and cowpeas), poor timing of pesticide application and a virtual absence of personal protective equipment amplify environmental and human health risks (Coulibaly & Lowenberg-DeBoer, 2014; Jepson et al., 2014; Ntow et al., 2006; Tano et al., 2011). Largely unmonitored, these risks pose potentially severe impediments to Africa's long-term efforts to raise farm productivity sustainably and ensure food security (Tamru et al., 2017, Haggblade, Minton et al., 2017).

4 | REGULATORY RESPONSES

4.1 | Regulatory reform chronologies in West Africa

Since 1994, nine Sahelian West African countries have registered pesticides jointly through a common regional regulator, the CSP. Over two and a half decades later, the Economic Community of West African States (ECOWAS) is currently attempting to replicate this regional regulatory model in the coastal West African countries. As a result, differing regulatory models have emerged for controlling pesticides, one in the arid interior zone and another in the humid coastal countries.

TABLE 7 Timing of major pesticide policy legislation in case study countries

Zone Country	Years major pesticide legislation enacted
Sahelian CSP members (ECOWAS Sahelian Zone)	
Gambia	1994, 2003
Mali	1995, 2001, 2002, 2009
Senegal	1984, 2002
Coastal countries (ECOWAS Humid Zone)	
Côte d'Ivoire	1974, 1989
Ghana	1994
Guinea	1992, 1996
Nigeria	1976, 1996, 2005

Source: Field interviews and legislative reviews in seven case study countries.

4.1.1 | Sahelian countries: Regional policies pave the way for national pesticide legislation

A series of large-scale pest invasions swept across the arid Sahelian region of West Africa following a sequence of devastating regional droughts in the 1970s. In 1973, to combat these threats, nine Sahelian countries formally established a regional organization called the Comité Permanent Inter-Etats de Lutte contre la Sécheresse dans le Sahel (CILSS) to manage a collective regional response to the droughts and, subsequently, the pest invasions as well. After over a decade of co-ordinated regional pest control efforts, the CILSS Council of Ministers of Agriculture adopted common regional pesticide regulations in 1992 (CILSS Resolution No. 7/27/CM/92).

To implement its regional pesticide regulations, the CILSS Council of Ministers created a regional regulatory body, the Comité Sahélien des Pesticides (CSP), to review applications from pesticide companies for the right to sell specific pesticide products throughout the nine CSP member countries.⁸ Under these regional regulations, any pesticide authorized by the CSP can be legally sold in all nine member countries. As a result, the CSP serves as a one-stop-shop for companies wishing to sell pesticides in any member countries (Abiola et al., 2004). Since its inception in March 1994, the CSP has functioned effectively as the Sahel-wide regional pesticide regulator due to a strong sense of trust and common purpose among the national phytosanitary services and a collective appreciation of the benefits of pooling scarce human, financial and laboratory resources. As of November 2019, the CSP had authorized 470 pesticide products for sale throughout the nine original CILSS member states (INSAH, 2019).

National pesticide legislation followed later. With the single exception of Senegal, the Sahelian countries first passed national legislation governing pesticides during the 1990s, after and in response to the 1992 CILSS regulations (Table 7). As a result of this sequencing, the Sahelian countries designed their national pesticide laws and regulations to conform with the CILSS regional regulations and formally embed them in national law (Diarra & Haggblade, 2017; Prado-Leal, 1999).

⁸In 2011, four francophone coastal countries (Benin, Côte d'Ivoire, Guinea and Togo) joined CILSS but not the CSP.

4.1.2 | Coastal countries: national regulations come first

In contrast, national pesticide regulations were introduced first in the humid coastal countries. In the absence of a common external threat and the collective experience of sustained joint pest control efforts, the coastal countries developed national pesticide legislation independently of one another. From the 1970s up to the 1990s, individual countries began to issue national legislation in response to growing pesticide use in the cash-cropping zones and in peri-urban horticulture (Table 7). Additional impetus emerged from the early 1980s onwards, when structural adjustment programmes led to the widespread dismantling of agricultural parastatals, which in prior decades had managed pesticide and other agricultural input supply in the cash-cropping zones (Kheralla et al., 2010; Williamson, 2003). As public control of pesticide (and other input) deliveries passed into private hands, African governments became increasingly motivated to formulate regulations governing the newly privatized agricultural input markets. These national regulatory agencies have operated independently of each other for up to five decades in the coastal countries.

Recently, ECOWAS attempted to extend the CSP's regional regulatory model to the coastal West African countries. In 2008, the ECOWAS Council of Ministers formally approved regional pesticide regulations (ECOWAS Regulation N°C/REG.3/05/2008) that called for the creation of a new West African Pesticide Registration Committee (WAPRC). Under WAPRC, the CSP would continue to function as the joint registration body for the nine Sahelian countries while a second, yet-to-be-formed regional sub-committee (WAPRC-Humid Zone) would serve as the joint registration body for the eight humid coastal countries.

Several anticipated benefits motivated this effort to expand regional pesticide regulation to the coastal countries (Traoré et al., 2011). Cost savings from the pooling of scarce technical personnel and laboratory facilities benefit the region's smaller countries, in particular (Davis, 2011). Regional markets also reduce testing and registration expenses for private firms and thereby expand pesticide products available, particularly in the smaller countries. Finally, a single regional registration platform offers the potential for reducing pesticide smuggling that has emerged as a result of conflicting national registration decisions by neighbouring countries. Ghana's national pesticide regulator, for example, has approved the herbicides paraquat and atrazine for sale domestically, while Côte d'Ivoire and the nine CSP countries have banned both active ingredients. This disparity has triggered a lively cross-border trade in contraband pesticides as smugglers deliver Ghanaian products into neighbouring countries where they are illegal (Yao, 2018, 2020).

Despite these expected benefits, the technical secretariat for the WAPRC-Humid Zone does not yet exist. Three major challenges have contributed to sluggish implementation of regional pesticide registration system in the coastal countries. First, because well-established national pesticide regulations already existed in the coastal countries by 2008, the resulting welter of conflicting national registration decisions requires harmonization. Secondly, conflicting legal interpretations of the authority of the ECOWAS regional regulations on national implementing agencies have stymied progress. Finally, financial constraints have arisen, because some national regulators in the coastal countries currently depend on pesticide application and registration fees and thus fear the loss of a key revenue source to the proposed new regional regulator. Thus, in spite of the anticipated benefits from regionally harmonized pesticide regulations, implementation has faced multiple practical difficulties.

4.2 | Alternative regulatory models across Africa

Outside the Sahel, most African countries regulate pesticides nationally. Under this default model, individual national governments and their national regulatory agencies assume responsibility for all

TABLE 8 Alternative regulatory models

Regulatory models*	Three phases of regulation		
	a) Pre-registration testing	b) Registration decision	c) Post-registration monitoring & enforcement
1. National	National	National	National
2. Harmonized testing protocols	National, using regional protocols	National	National
3. Regional registration	National, using regional protocols	Regional	National
4. Regional registration and monitoring	Regional protocols by agricultural zone	Regional	Regional environmental monitoring, sentinel sites

*Shading indicates regional harmonization.

Source: authors.

three phases of pesticide market regulation: (a) pre-registration efficacy and toxicity testing; (b) registration decisions and associated scientific review; and (c) post-registration monitoring of markets, product quality, regulatory compliance and impacts on human health and the environment (Table 8, Model 1). Africa's three largest economies—Egypt, Nigeria and South Africa—all regulate pesticides nationally. Their large domestic markets readily attract commercial interest from international agro-chemical firms. These leading economies, similarly, boast strong scientific establishments capable of conducting pesticide testing, scientific review and new product assessment as well as post-registration monitoring of formulation verification testing, environmental and human health impact.

Africa's many small countries, however, possess neither the scientific resources necessary to manage pesticide assessments on their own nor the market scale necessary to attract commercial interest by international firms (Byerlee & Traxler, 2001; Collier, 2009; Gerard, 1996; Hagglade, 2013). Africa's small country problem has emerged in stark relief during the recent FAW invasion, as many small African countries have struggled to attract interest by international companies in testing new pesticide products suitable for combatting this new threat (EAC, 2019).

The regional pesticide registration model pioneered by the nine founding CSP member countries has attracted interest from across Africa as a possible organizational model for overcoming Africa's small-country problem by pooling scarce technical personnel and laboratory facilities to attain scientific critical mass and sufficient market scale to attract interest from private firms. Under the CSP model (Table 8, Model 3), national research institutions conduct pre-registration efficacy and toxicity testing using standard regional protocols. Firms wishing to sell a new pesticide formulation in any member country then submit a single application for joint review by a technical review panel composed of two scientists from each of the nine member countries at the CSP secretariat in Bamako, Mali. Following registration approval by the CSP, post-registration monitoring of product quality and environmental impacts becomes the responsibility of individual national government agencies. In Southern Africa, a similar arrangement links the Republic of South Africa (RSA) with the smaller regional economies of Lesotho, Swaziland, Namibia and Botswana, all of whom accept South African-registered pesticides for sale domestically (Table 9).

An intermediate, possibly transitional, model has attracted significant interest across several regional economic groupings in Africa. Model 2, a sort of "CSP-lite," involves regionally standardized pre-registration testing protocols which are then used by national regulators in making their own individual registration decisions. Five coastal West African countries of Benin, Côte d'Ivoire, Ghana,

TABLE 9 Adoption of alternative pesticide regulatory models

Regulatory models	West Africa		Other Africa Regions
	In theory	In practice	In practice
1. National		Other coastal (3)	North Africa (5) Central Africa (8) Southern Africa, large (3)
2. Harmonized testing protocols		Coastal HIP (5)	EAC (5)
3. Regional registration	Coastal countries (8) Sahel CSP (9)	Sahel CSP (9)	RSA-plus (4)
4. Regional registration, regional monitoring		None	None

Legend:

West Africa, Other Coastal: Nigeria, Liberia, Sierra Leone

West Africa Coastal HIP: Benin, Côte d'Ivoire, Ghana, Guinea, Togo

West Africa Sahel CSP: Burkina Faso, Cape Verde, Chad, Gambia, Guinea-Bissau, Mali, Mauritania, Niger, Senegal

North Africa: Morocco, Algeria, Tunisia, Libya, Egypt

Central Africa: Cameroon, Central African Republic, Congo, Democratic Republic of Congo, Gabon

Southern Africa, large: Republic of South Africa (RSA), Zambia, Zimbabwe (Botswana, Namibia in process)

East African Community (EAC): Burundi, Kenya, Rwanda, Tanzania, Uganda

RSA-plus: Lesotho, Swaziland, Botswana*, Namibia* all accept RSA registered products for sale domestically

* National registration in process.

() Number of countries in each grouping listed in parentheses.

Sources: Regional stakeholder consultations with regulators from West, East and Southern Africa (see Section 2.2).

Guinea and Togo have adopted standardized testing protocols and application forms developed jointly under a regional donor project in the late 1990s. Similarly, most Southern African countries currently accept testing results conducted in RSA in submissions for regulatory approval (S. Simiyu, personal communication, November 26, 2019). More recently, in August 2019, the East African Community (EAC) formally agreed to institute standardized pesticide testing protocols across member countries of Kenya, Tanzania, Uganda, Burundi and Rwanda. While not as economical as the CSP's one-stop-shop regional registration, the standard testing protocols at least hold out the promise of reducing testing costs for submitting firms and thereby expanding commercial interest in groupings of small African markets. The FAW emergency motivated EAC decision-making as a means of encouraging private sector response to the rapidly unfolding pest emergency (EAC, 2019).

A fourth possible model involves expanding the CSP's regional registration system to include regional monitoring of environmental and human health impacts. The aim here would be to economize on the most expensive and technically demanding portion of post-registration monitoring of residue levels, environmental and human health impacts impact though the selection of a handful of representative sentinel sites across a given region (Thériault et al., 2020).

4.3 | Common weaknesses in post-registration monitoring

Under all regulatory models, the weakest link in African pesticide regulatory systems lies in their often feeble post-registration monitoring of traders, markets, product quality, and impact on human health and the environment. The frequent appearance of fraudulent pesticides in some markets provides

visible testament to the uneven and often inadequate enforcement of pesticide regulations in many African settings (Ashour et al., 2018; Haggblade, Keita et al., 2019; MIR Plus, 2012; Murphy et al., 2012; Rodenburg, 2019).

In part, differing ministerial designations of responsibility for regulatory enforcement lead to differing priorities and concerns. Across the case study countries, institutional responsibility for enforcing pesticide regulations varies significantly. Three of the countries (Côte d'Ivoire, Guinea and Mali) regulate pesticides primarily through the Ministry of Agriculture, while three others (Gambia, Ghana and Senegal) assign principal responsibility to the Ministry of Environment, and one (Nigeria) designates the Ministry of Health as their lead pesticide regulator. These institutional differences affect regulatory staffing resources, technical skill sets and enforcement priorities. While ministries of agriculture typically view pesticides as necessary inputs for raising farmer productivity, ministries of environment and health view pesticides primarily as dangers to their constituents.

Regulators trying to monitor pesticide quality, quantities used and residue levels likewise face significant technical constraints. Recent technical assessments suggest that laboratory capacity remains limited, particularly in smaller countries, and quality control procedures uncertain (duBois, 2018; Jiang, 2019). When our team recently submitted pairs of blind duplicate glyphosate samples to three independent testing laboratories, only one of the three laboratories produced comparison results within normal expected levels of scientific accuracy (Haggblade, Diarra et al., 2019). These experiences suggest that investments in laboratory testing facilities and quality control procedures constitute an important prerequisite for effective monitoring of pesticide formulation, food quality and environmental residues.

Finally, despite sharply increasing pesticide use (Figure 1), the environmental impact of this increased pesticide volume remains largely unmonitored. Occasional individual studies conducted by local researchers, graduate students or donor projects provide welcome-but-intermittent glimmers of evidence about pesticide exposure and residue levels.⁹ Yet these irregular, episodic studies do not provide ongoing or comprehensive assessments of on-the-ground conditions in West Africa's rapidly intensifying agricultural production zones. Stakeholders interviewed across the region readily acknowledge that the rapid rate of recent pesticide market growth has outpaced regulatory capacity to monitor product quality, safety, and environmental impact.

4.4 | Private sector reactions to weak regulatory enforcement

Farmers, and the organizations that support them, have a strong vested interest in combatting fraudulent pesticides and ensuring formulation quality. Registered input suppliers who comply with regulatory testing and review requirements also face strong commercial incentives to root out fraudulent pesticides, since unregistered and counterfeit products take market share from their duly tested and registered brands. In the face of often limited public regulatory capacity, these aggrieved parties have begun to fight back.

Leading these efforts, major importers of legally registered pesticide brands have launched a series of media outreach, stakeholder training and legislative lobbying campaigns to combat fraudulent pesticides in key markets across West Africa (Yao, 2018, 2020). Pesticide industry associations have funded a series of anti-fraud media campaigns including television sketches, radio programming, newspaper features and press conferences at national and regional conferences. From 2013 to 2015,

⁹See, for example, Chouaïbou et al. (2016), Dieng (2012), Donkor et al. (2016), Jepson et al. (2014), Keita (1992), and others reviewed by Theriault et al. (2020).

pesticide industry groups convened a series of cross-border training workshops involving pesticide regulators as well as customs and police officials in Ghana and in Côte d'Ivoire. These industry groups have also worked with national regulators to enact legislative reforms in Côte d'Ivoire leading to the formation of district pesticide committees through which local authorities, farmer groups, traders, agricultural ministries, customs and police share information on fraudulent pesticides and so target enforcement efforts. Together, organizers believe these efforts have reduced fraudulent pesticides on sale in Côte d'Ivoire perceptibly, from about 40% to 20% (Yao, 2020). Though precise numbers are difficult to verify, the public and private sector stakeholders we interviewed generally confirm a significant reduction in fraudulent pesticide sales following these joint private–public sector anti-fraud campaigns. Taken together, these private sector efforts suggest broad interest among key stakeholders in improving regulatory enforcement and combatting fraudulent pesticides.

5 | POLICY LESSONS FROM THE FIRST WAVE OF PESTICIDE MARKET GROWTH

As the fall armyworm invasion spreads across Africa, initial responses have focused on emergency applications of highly toxic insecticides, which exacerbate environmental pressures and human health risks (Bateman et al., 2018; FAO, 2019a, 2019b; Murray et al., 2019; Prasanna et al., 2018). As this new source of pesticide demand continues to build, several lessons from the prior wave of pesticide growth may help policy-makers to manage this expansion in pesticide sales more effectively.

5.1 | Short-run opportunities for improvement within existing regulatory structures

5.1.1 | Stakeholder coalitions for combatting fraudulent pesticides

In the face of limited public resources for regulatory enforcement, the most promising short-term model our field team has observed for reducing high levels of fraudulent pesticides involves location-specific anti-fraud campaigns conducted by coalitions of regulators, private traders, farmer groups, and allied stakeholders. Expansion of similar initiatives to new locations can now draw on a growing body of empirical evidence on fraud levels, dosage rates, marketing behaviour and known bad actors (Ashour et al., 2018; Haggblade, Diarra et al., 2019; Haggblade, Keita et al., 2019; MIR Plus, 2012; Yao, 2018, 2020). Organizationally, these anti-fraud efforts could profitably emulate the decentralized model of regulatory monitoring and enforcement developed collaboratively by private and public sector stakeholders in Côte d'Ivoire.

5.1.2 | Environmental monitoring in regional sentinel sites

Currently, post-registration monitoring of pesticide markets, product formulations and resulting public health and environmental risks remains the weakest component of African regulatory systems. These limitations stem, in part, from the high cost of monitoring and, in part, from the modest regulatory resources available to national entities charged with this task. Given that environmental impacts occur over time, in multiple biological systems (plants, soil, water, insects, animals and humans), monitoring can quickly become complex and costly. The CSP model of regional regulatory review

intentionally economizes on scarce scientific personnel and laboratory facilities in vetting pesticide products prior to release. Parallel economies may well exist for post-registration environmental monitoring through regional selection of representative sites across common agro-ecological zones. Rather than expecting all 17 ECOWAS countries to launch 17 individual monitoring systems, a regional sampling of common high-risk cropping systems could offer an economical model for post-registration environmental and health monitoring.

5.1.3 | Integrated pest management

In order to minimize the risks posed by synthetic pesticides to human health and the environment, most pest control specialists encourage a suite of IPM practices that discourage the development of pest populations through a locally tailored combination of improved agronomic practices, natural pest control mechanisms, biological control products, and small-but-targeted doses of synthetic pesticides (Bateman et al., 2018; FAO, 2018; Jepson et al., 2020). Expansion of these efforts will require affirming policy signals as well as increased resources for research, outreach and training in IPM strategies. In return, IPM initiatives offer potential benefits to the environment, farm sustainability and public health. Such a reorientation would also help to relieve pressure on overworked, underfunded pesticide regulators in Africa.

5.2 | Medium-term responses: Strengthening regulatory systems

5.2.1 | Regional harmonization

Regional harmonization of pesticide testing protocols (as in Model 2) offers significant cost reductions for private firms, enabling them to submit a single set of testing results to access multiple markets at a single stroke. Harmonized registration decisions (as in Model 3) offer further cost savings for private firms as well as significant opportunities for regulatory cost savings through the pooling of scarce scientific resources across countries. Model 3 offers the further benefit of limiting incentives for smuggling that arise under the fragmented, conflicting registration decisions currently in force in coastal West Africa and elsewhere. For these reasons, small countries and regional economic commissions (RECs) throughout Africa are actively communicating with West Africa's CSP to identify levels of regional harmonization that will best serve their regulatory needs (EAC, 2019; INSAH, 2019; SADC, 2019).

5.2.2 | Expanding resources for post-registration enforcement

Currently, financial and human resource constraints severely limit the capacity of African pesticide regulators to perform their legally mandated post-registration monitoring functions. National regulators rely primarily on annual government budget allocations, supplemented, in some cases, by product registration fees. Yet most national budget allocations have not kept pace with the rapid growth in pesticide markets.

Regional regulators face similar resource pressures. Indeed, the absence of a clear financing plan has largely stalled the establishment of the WAPRC-Humid Zone secretariat for the coastal West African countries. The Sahel's CSP has historically self-financed, supporting its small technical staff

and annual operating expenses solely from product registration and application fees. Though financially sustainable, this model leaves the CSP vulnerable to industry pressure; should the major firms informally agree to stop submitting product registration applications for even a single year, the CSP's budget resources would collapse. Moreover, reliance on pesticide application fees requires high rates which, in turn, increase incentives for suppliers to circumvent the regulatory system, as many already do. Hence the importance of identifying an expanded mix of funding sources—government budget allocations, registration and testing fees, import levies and professional fees—that will increase the overall resource base for regulatory activities.

5.2.3 | Laboratory upgrading

Farmers and traders complain that the current proliferation of unregistered pesticide products leads to unpredictable variations in pesticide quality and widespread suspicion of under-dosing. A shortage of accredited testing laboratories complicates verification of these complaints. Recent diagnostic visits to laboratories across West Africa identify support required for equipment upgrading, staff training and accreditation processes necessary to improve testing protocols and quality control procedures (duBois, 2018; Jiang et al., 2019). Given West Africa's many small countries, a system of regional reference laboratories will likely prove necessary to economize on scarce technical resources, particularly in the smaller countries. Despite strong interest by CSP and ECOWAS authorities, resource constraints have, to date, stymied efforts to support a system of regional reference laboratories.

6 | CONCLUSIONS

Agricultural intensification places stress on regulatory systems. The evidence reported here indicates that rapid recent growth in West African pesticide markets has caught many regulators flat-footed and under-resourced. As a result, fraudulent pesticides of highly variable quality now circulate freely in many local markets. Confused farmers, in turn, face difficulties identifying properly dosed products necessary to raise farm productivity. Fraudulent pesticides, because of their unknown quality and composition, pose potentially serious environmental and human health risks. Successful agricultural intensification will, therefore, require improved enforcement of existing policies and regulations in order to guarantee the quality and safety of farm inputs.

In prior decades, serious pest invasions have motivated major reforms in pesticide regulatory systems, most notably the launch of the CSP's regional regulatory model which has, in turn, inspired recent efforts at emulation. The current invasion of an exotic pest opens a window of opportunity for concerned stakeholders in the private sector, the farming community and public agencies to mobilize the political will and resources necessary to strengthen Africa's pesticide regulatory systems. The experiences summarized here, from West Africa's first wave of pesticide market growth, offer insights that can help to improve regulatory policy implementation and inform necessary future reforms across Africa.

ACKNOWLEDGEMENTS

The authors are grateful to the hundreds of key informants, traders, farmers, regulators and researchers who patiently answered our many questions about pesticide markets in West Africa during the course of our country studies and related field work. Local collaborators Josué Raphaël Adegbiđi, Ousmane

Diakité, Sène Waly Binetou Fall, Akamou Fataye, Naman Keita, Sonko Landing, Abdoulaye Ndiaye and Eric Bentsil Quaye provided invaluable substantive and logistic support. Industry stakeholders participating in a series of workshops convened by the Comité Sahélien des Pesticides (CSP), by Croplife International and by the US Department of Justice provided valuable feedback on our early research results and have helped to solidify and refine our understanding of West Africa's pesticide markets and regulatory systems.

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How to cite this article: Haggblade S, Diarra A, Traoré A. Regulating agricultural intensification: Lessons from West Africa's rapidly growing pesticide markets. *Dev Policy Rev.* 2021;00:1–24. <https://doi.org/10.1111/dpr.12545>