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Sustainable alternatives and best management practices for agrochemical use in Rivers Niger and Kaduna catchments: Farmer perspectives and feasibility assessment

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Abstract

Reducing dependence on synthetic agrochemicals whilst maintaining agricultural productivity requires the identification and promotion of locally appropriate alternatives suited to the knowledge, resources and priorities of smallholder farmers. This study assessed the feasibility of sustainable alternatives to synthetic pesticide and fertilizer use in parts of the Rivers Niger and Kaduna catchments, north-central Nigeria. Twenty-four farmer focus groups and a household survey of 350 respondents documented existing sustainable practices, adoption interest and perceived barriers for six alternative approaches. Sixty-eight per cent of farmers expressed willingness to adopt alternatives provided productivity equivalence could be demonstrated. Integrated pest management (IPM) received the highest adoption interest (71 per cent), followed by improved crop rotation (56 per cent) and botanical pesticides derived from neem (49 per cent). Primary adoption barriers were absence of extension support (79.2 per cent of focus groups) and yield uncertainty (75.0 per cent). On-farm demonstration plots were the strongly preferred learning mechanism (86 per cent of respondents). The study concludes that IPM and improved crop rotation represent immediately feasible alternatives for scale-up in the study area, with neem-based botanical pesticides requiring additional technical extension support. Investment in demonstration infrastructure and extension capacity is the critical enabling condition for adoption.

Keywords: Agroecology, Botanical pesticides, Crop rotation, Extension services, Farmer adoption, Integrated pest management, Neem, Sustainable agriculture.

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Contents

Contribution of this paper to the literature

This study provides the first systematic, farmer-centred feasibility assessment of sustainable agrochemical alternatives in the Rivers Niger and Kaduna catchments, Nigeria. It documents existing practices, adoption willingness under productivity-risk conditions, institutional barriers and preferred extension mechanisms, generating locally grounded evidence not previously available for programme design in this under-researched riparian agricultural system.

1. Introduction

The intensification of synthetic agrochemical use in smallholder African agricultural systems over the past two decades has delivered substantial short-term productivity benefits but at high environmental and health costs [1]. Water quality degradation, loss of aquatic biodiversity and exposure of farming communities to toxic pesticide residues are well-documented outcomes of agrochemical intensification in riparian agricultural systems [2]. Sustainable reduction of chemical inputs requires a transition to integrated approaches that manage pests and soil fertility through ecological processes supported by minimal chemical inputs.

Integrated pest management (IPM) is internationally recognised as the most effective framework for sustainable pest control, combining cultural, biological, physical and chemical control tactics in a way that minimises pesticide use whilst maintaining economically acceptable crop protection outcomes [3]. However, IPM adoption rates among smallholder farmers in sub-Saharan Africa have been generally lower than anticipated following the extensive Food and Agriculture Organization (FAO) farmer field school programmes of the 1990s and 2000s [4]. Research consistently identifies lack of extension support, cost uncertainty and perceived risk as the principal constraints to adoption [5]. In Nigeria, national agricultural policies formally endorse IPM and sustainable agriculture, but extension resources to promote adoption are critically inadequate [6].

In the Rivers Niger and Kaduna catchments, heavy synthetic agrochemical use has resulted in documented pesticide contamination of water, sediment and aquatic organisms, with implications for human health and ecological integrity. Regulatory enforcement is insufficient to constrain use, making voluntary farmer adoption of less contaminating alternatives the principal pathway to environmental improvement. This study provides the first systematic assessment of sustainable alternative feasibility and farmer adoption intentions in the study area, to support programme design by extension services and relevant government agencies [6].

The case for a transition to sustainable alternatives in the Rivers Niger and Kaduna catchments rests on a well-documented record of harm. Investigations in the study area have confirmed that farmers apply synthetic fertilizers at rates reaching one hundred and seventy kilogrammes per hectare and pesticides at rates exceeding ten litres per hectare, substantially above agronomic recommendations, and that a large share of the pesticide formulations in use are organochlorine compounds that are persistent, bioaccumulative and, in several cases, banned or restricted in Nigeria. Laboratory analysis of water and sediment across all five agroecological zones detected residues of endosulfan, lindane, methoxychlor and related organochlorine compounds, alongside nitrate, nitrite and phosphate concentrations attributable to fertilizer use, with the heaviest loading recorded in the downstream lower zones. This contamination has proceeded in the near absence of effective regulatory constraint.

Against this background, the promotion of ecologically based alternatives is not merely an agronomic preference but an environmental and public health necessity. The communities of the study area depend on the rivers for drinking water, domestic use and fishing, and the same investigations that documented contamination also recorded a substantial community health burden and consequent economic hardship attributable to agrochemical use. Reducing chemical inputs while safeguarding the food security and incomes of resource-poor farmers therefore requires alternatives that are technically sound, locally appropriate and, above all, credible to farmers as means of maintaining productivity. The feasibility of such alternatives cannot be assumed from their performance in experimental or foreign settings; it must be assessed against the knowledge, resources, priorities and risk tolerance of the farmers who would be asked to adopt them.

It is significant that the study communities are not without relevant experience. Field enumeration established that several ecologically based practices already exist within the farming system at limited scale, including informal crop rotation, the use of farm manure as a soil amendment and the occasional application of neem leaf extracts for pest control. These existing practices, although rarely framed by farmers as sustainability strategies, provide a foundation of partial familiarity upon which structured extension programmes can build. The present study therefore proceeds from an assessment of what farmers already do, through an evaluation of their interest in a defined set of alternatives, to an analysis of the barriers that must be removed and the delivery mechanisms that farmers themselves prefer, so that recommendations are grounded in the expressed priorities of the intended adopters rather than imposed from outside [6].

2. Literature Review

Synthetic agrochemical use in sub-Saharan African smallholder farming systems has intensified markedly over the past two decades, generating well-documented environmental and health consequences. Aktar, et al. [7] reviewed global pesticide use patterns and found that developing countries bear a disproportionately high share of pesticide-related health impacts relative to their share of agricultural output, a disparity driven by deficient safety infrastructure, inadequate regulation and absence of protective equipment. In Nigerian riparian systems specifically, Mohamed, et al. [1] documented the degradation of water resources through agricultural pesticide and nutrient loading, confirming the same contamination pathways that the present study area exhibits.

The scientific basis for IPM as the preferred framework for sustainable pest control is firmly established. Peshin and Dhawan [8] synthesised global evidence on IPM adoption and concluded that the framework consistently reduces pesticide use by forty to sixty per cent without yield penalties where adequate extension support is provided. Abate, et al. [9] demonstrated IPM effectiveness specifically in African cereal systems, documenting significant reductions in both pest damage and pesticide expenditure through the combined deployment of resistant varieties, biological control and cultural controls. However, Pretty and Bharucha [3] noted that sustaining IPM adoption beyond initial programme periods remains the central unresolved challenge, and that the collapse of farmer field schools after FAO programme withdrawal in the 1990s and 2000s illustrates the dependence of adoption on continued institutional support.

The role of extension services in technology adoption is foundational to the agrarian development literature. Anderson and Feder [10] reviewed agricultural extension systems globally and found that the single most consistent predictor of sustained adoption of new farming technologies was ongoing contact between farmers and trained extension agents, and that one-off training events generate knowledge without durable behaviour change. Palis, et al. [4] confirmed this finding specifically for IPM in Asian smallholder settings, demonstrating that farmers who maintained contact with farmer field school networks after formal programme completion showed significantly higher sustained IPM adoption rates than those who did not.

The adoption of neem-based botanical pesticides has attracted substantial research interest as a low-cost, locally available alternative to synthetic compounds across West Africa. Isman [11] reviewed the global evidence on plant-based insecticides and concluded that neem seed kernel extract (NSKE) provides effective control of a broad range of agricultural pests at application rates economically viable for smallholder farmers, and that its residual activity, environmental persistence and mammalian toxicity profile are all substantially more favourable than those of the organochlorine and organophosphate compounds it is most commonly used to replace. The principal constraint to adoption, consistent with findings from multiple countries, was preparation knowledge rather than resource availability.

Crop rotation as a soil fertility and pest management strategy is among the oldest and most widely validated agricultural practices. Hobbs, et al. [12] reviewed long-term rotation trials and found that legume-cereal rotations reliably reduce synthetic fertilizer requirements by fifteen to thirty per cent through biological nitrogen fixation, while simultaneously suppressing soil-borne pathogens. Vanlauwe, et al. [13] demonstrated in West African farming systems that integrated soil fertility management, combining rotation with modest organic amendment, outperformed exclusive synthetic fertilizer use in both yield and soil health indicators over multi-season trials, with the advantage increasing over time. These findings are directly relevant to the study area, where maize-bean-groundnut rotations already exist informally.

The diffusion of agricultural innovations follows well-theorised patterns. Rogers [14] established that adoption proceeds through a recognisable sequence from awareness through trial to full adoption, and that the perceived attributes of an innovation, particularly its observability and the ease with which potential adopters can trial it at limited risk, are stronger predictors of adoption than its objective technical merits. This framework has been applied extensively to IPM promotion, where Heong, et al. [15] found that farmer field schools accelerate diffusion precisely because they provide the observability and low-risk trialling that Rogers identifies as adoption accelerators, while conventional extension lectures do not.

Participatory approaches to agricultural technology development are consistently shown to generate higher adoption rates than technology transfer approaches. Chambers, et al. [16] demonstrated that farmer participation in the design and testing of new practices builds ownership, local adaptation and the peer-network diffusion on which sustainable scale-up depends, and that externally designed technologies introduced without participatory adaptation routinely fail to achieve lasting adoption even when their technical merits are demonstrated. This evidence base supports the participatory focus group and household survey methodology employed in the present study and underpins the argument that recommendations grounded in farmer-expressed priorities are more likely to be adopted than those derived from agronomic science alone.

3. The Study Area

The study area encompasses communities across parts of Rivers Niger and Kaduna catchments in Niger State (Longitude 3°30'E to 7°20'E; Latitude 8°22'N to 11°30'N). Agriculture is the principal livelihood activity, with rice, maize, beans, groundnut and melon as major crops. The study area is zoned into three zones along River Niger and two zones along River Kaduna based on agroecological factors, as shown in Figure 1. Previous studies have established that synthetic agrochemical use is pervasive and associated with water quality degradation in all five zones.

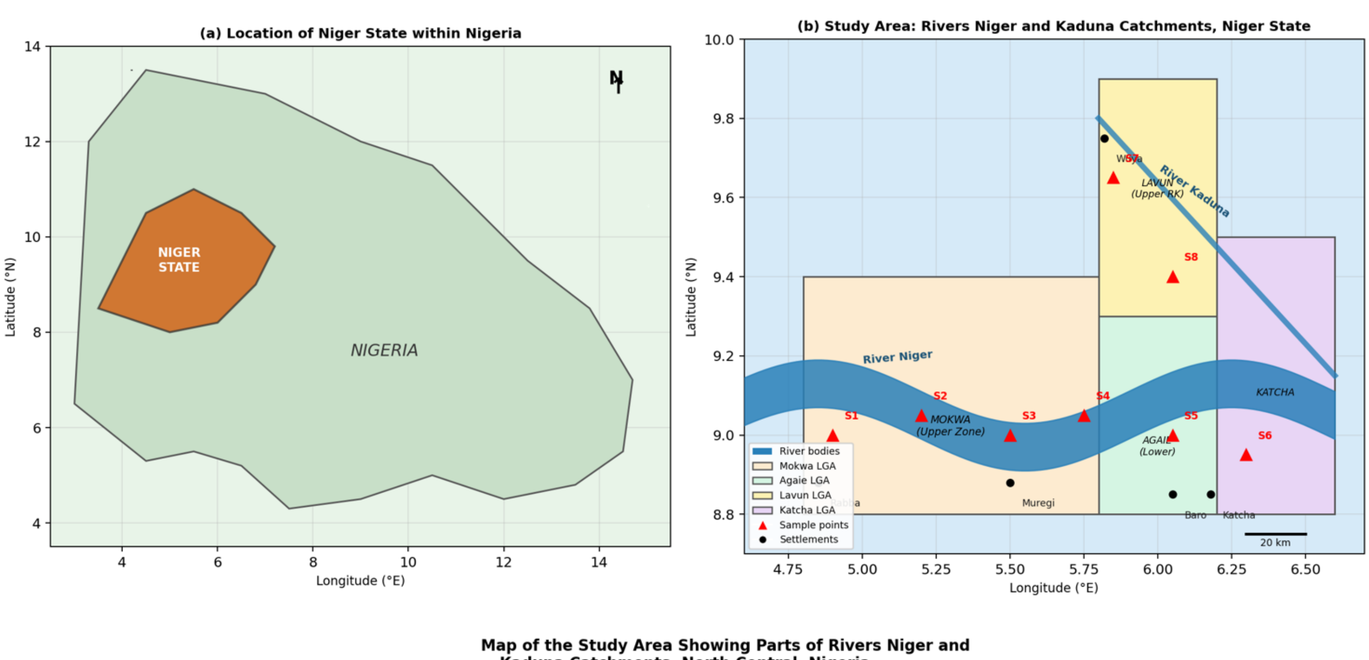

Figure 1. Map of the Study Area Showing Rivers Niger and Kaduna Catchments, Community Locations and Agroecological Zones Where Participatory Assessments Were Conducted.

The farming system across the five zones is dominated by smallholder subsistence and semi-commercial producers cultivating holdings of between two and fifteen hectares, many of which have been under continuous cultivation for more than three decades. This long history of cultivation, combined with limited use of organic amendments, has contributed to declining soil fertility and to the escalating dependence on synthetic inputs that the transition to sustainable practice must reverse. Rice, maize, beans, groundnut, millet and melon are the principal crops, cultivated predominantly in the rainy season, when moisture is abundant and inputs are cheaper, with a smaller dry season cropping cycle and, for certain crops, up to three plantings within a single year.

Livestock holdings in the area are limited, which constrains the availability of farm manure and helps to explain both the historic drift towards synthetic fertilizers and the ceiling on the scale at which organic amendment alone could substitute for chemical inputs. Fishing is the second principal livelihood, which gives the communities a direct material interest in the ecological recovery of the rivers and provides a potential source of motivation for the adoption of less contaminating practices. These characteristics of the farming system, its subsistence orientation, its intensive cropping calendar, its limited livestock base and its dependence on rivers that are simultaneously a water source and a fishery, together define the conditions under which any sustainable alternative must prove itself viable.

4. Materials and Methods

4.1. Participatory Focus Group Assessment

Participatory rural appraisal techniques were employed, including 24 farmer focus groups with 12 to 18 participants each, conducted in communities across all agroecological zones. Focus groups followed structured but flexible guides exploring: perceptions of current agrochemical benefits and drawbacks; knowledge of sustainable alternatives; perceived constraints; willingness to experiment; and preferred learning approaches [17]. Discussions were conducted in Hausa or Nupe language by local facilitators, documented through detailed note-taking and participant mapping exercises.

The composition of the focus groups was deliberately varied to capture the perspectives of farmers differing in age, holding size and prior contact with extension services, since preliminary observation suggested that adoption attitudes were unlikely to be uniform across these categories. Facilitators were trained to maintain a neutral stance, to avoid leading participants towards particular answers and to probe the reasoning behind stated positions, so that the discussions yielded not only expressions of interest or reluctance but the underlying rationale on which programme design could act. Participant mapping exercises were used to record the spatial distribution of existing practices and of natural resources such as neem trees, which are material to the feasibility of botanical pest control.

4.2. Household Survey

A structured questionnaire was administered to 350 farmers randomly selected from the same population. The instrument documented: current use of any sustainable practices; knowledge of six specific alternatives (IPM, improved crop rotation, organic amendment, agroforestry, botanical pesticides, cover cropping); willingness to adopt under various productivity and cost scenarios; perceived barriers; and preferred extension delivery mechanisms. Binary and Likert-scale items were supplemented by open questions to capture farmer-articulated rationale [18].

4.3. Data Analysis

Focus group data were analysed thematically, with themes developed inductively and frequency-weighted across the 24 groups to identify the most widely held perspectives [19]. Survey data were analysed using Statistical Package for the Social Sciences (SPSS) version 23 with descriptive statistics and chi-square tests examining associations between farmer characteristics and adoption willingness, with statistical significance set at $p<0.05$.

5. Results and Discussion

5.1. Existing Sustainable Practices

Documentation of current practices revealed that several sustainable approaches are already in use at limited scale (Table 1). Crop rotation was the most widely practiced, employed by 42 per cent of respondents, typically rotating maize with beans and groundnut. Most rotations were informal and not framed as sustainability strategies but were driven primarily by soil depletion concerns. Farm manure use was reported by 38 per cent of farmers, constrained by limited livestock holdings in the area. Neem tree access was noted by 34 per cent of farmers and occasional use of neem leaf extracts for pest control was reported informally. Agroforestry integration was minimal at 6 per cent, limited to fruit trees. These baseline practices provide an important foundation upon which extension programmes can build, as farmers already have partial experience with the principles involved.

The character of the existing crop rotation practice merits closer attention because it represents the most promising foundation for scale-up. Farmers in the area already rotate maize with beans, groundnut, sorghum, melon and pepper, but they do so informally and in response to perceived soil depletion rather than as a deliberate strategy for pest suppression or fertility management. Because the leguminous components of these rotations fix atmospheric nitrogen and interrupt pest and disease cycles, the practice already delivers a share of the benefits that a formalised rotation would provide, and the task of extension is therefore one of refinement and encouragement rather than introduction from a standing start. The principal constraints reported were the additional labour that structured rotation demands and the reliability of input supply for the rotational crops.

Neem access presents a comparable opportunity. A significant proportion of farmers reported access to neem trees, and informal use of neem leaf extracts for pest control was already reported in the communities, yet formal preparation of neem-based botanical pesticide was practised by only a small minority. The gap between access to the raw material and its systematic use as a pest management input is explained by the absence of preparation knowledge and extension guidance rather than by any shortage of the resource itself. This distribution of existing practice, in which the biological and material foundations are present but the technical knowledge to exploit them is not, recurs across several of the alternatives assessed and points consistently towards knowledge transfer, rather than resource provision, as the binding constraint on adoption.

Table 1. Existing Sustainable Practices, Current Adoption and Interest in Scaling Up Among Farmers in the Study Area (n=350).

Practice	Currently Practiced (%)	Adoption Interest (%)	Principal Adoption Barrier
Formal crop rotation (maize, bean, groundnut)	42.0	56.0	Labour requirement and input supply
Use of farm manure as soil amendment	38.0	44.0	Limited livestock holdings in area
Neem-based botanical pesticide preparation	6.3	49.0	Lack of preparation knowledge and extension guidance
Trap cropping for pest management	2.9	64.0	No technical knowledge; no extension support
Mulching for weed suppression	18.6	58.0	Labour intensity; material availability
Agroforestry integration (trees on farm)	6.0	21.0	Land availability; long-term investment horizon
Cover cropping between seasons	4.3	32.0	Seed supply; uncertainty about productivity benefit

5.2. Interest in Sustainable Alternatives

When presented with information on six sustainable alternatives, 68 per cent of respondents expressed overall willingness to consider adoption if productivity equivalence could be demonstrated. IPM received the highest adoption interest at 71 per cent, followed by improved crop rotation (56 per cent) and botanical pesticides from neem (49 per cent), as illustrated in Figure 2. Interest in agroforestry was lowest at 21 per cent, reflecting concerns about land commitment and the long-time horizon before productivity benefits accrue [5]. When adoption willingness was tested against a yield reduction scenario ('would you adopt this practice even if the first-year yield was lower?'), support dropped from 68 per cent to 24 per cent. This confirms that adoption decisions are tightly constrained by short-term food security and income needs, consistent with technology adoption literature for resource-poor farmers in developing countries [14].

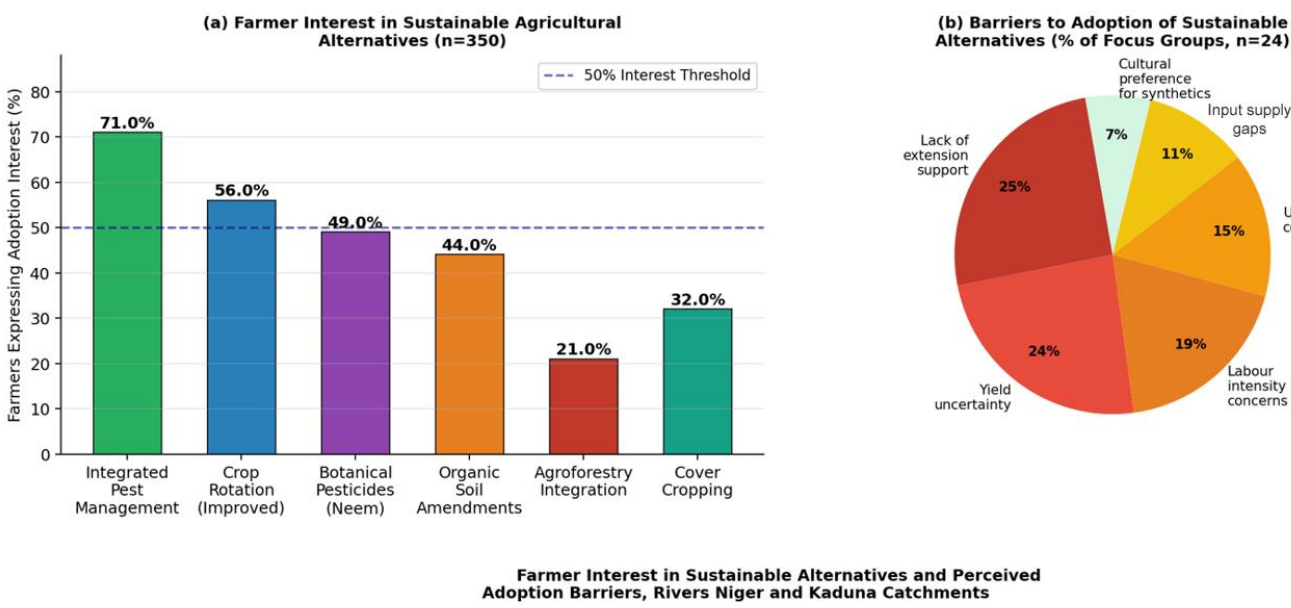

Figure 2. Farmer Interest in Sustainable Agricultural Alternatives and Perceived Adoption Barriers, Rivers Niger and Kaduna Catchments (n=350 for survey; n=24 focus groups for barriers).

This sensitivity to first-year risk is consistent with the measures that farmers themselves nominated for reducing agrochemical contamination when the question was put to them directly. The most favoured measure was the planting of early-maturing crop varieties, followed by increased awareness of the proper handling of agrochemicals, with continued general awareness of agrochemical dangers ranked lowest. The prominence of early-maturing varieties is revealing, because it indicates a preference for solutions that reduce exposure to pests and to the length of the vulnerable growing period without requiring farmers to abandon familiar practice or to accept output risk. Any programme of sustainable alternatives that incorporates improved, early-maturing and pest-resistant varieties therefore aligns with a preference the farmers have already expressed, and stands a correspondingly higher chance of acceptance than measures perceived as purely restrictive.

The ranking of awareness of proper handling above general awareness of danger carries a parallel lesson. Farmers distinguished, in effect, between information that equips them to act more safely and information that merely warns them of hazards they feel unable to avoid, and they valued the former more highly. This mirrors the finding from the companion behavioural study that risk information alone does little to change practice, and it reinforces the case for extension content that is practical and skills-based rather than admonitory. Sustainable alternatives are best presented, on this evidence, not as prohibitions on chemical use but as concrete, learnable techniques that deliver visible benefits, an orientation that the strong preference for on-farm demonstration further confirms.

5.3. IPM Component Analysis

Given the high adoption interest in IPM (71 per cent), specific IPM components were assessed in detail (Table 2). Trap cropping received the highest adoption willingness (64 per cent) despite only 38.6 per cent of farmers being aware of this technique, suggesting that once introduced, it is perceived as feasible. Mulching for weed and moisture management received 58 per cent adoption willingness, with most farmers recognising the technique from traditional practice. Biological control and threshold-based pesticide timing received lower interest (38 and 42 per cent respectively), reflecting the specialised knowledge required. Resistant crop varieties attracted 55 per cent adoption interest, contingent on improved seed supply access.

The pattern that emerges from the component analysis is instructive for sequencing. The techniques attracting the highest adoption willingness, namely trap cropping and mulching, are also those that make the lightest demands on external inputs and specialised knowledge, relying on locally available materials and accessible seed and requiring only farmer training rather than continuing technical support. By contrast, the techniques attracting lower willingness, biological control using predatory insects and threshold-based timed application, depend on identification skills and crop scouting competence that presuppose sustained extension contact of a kind that the study area does not currently possess. This alignment between adoption willingness and input intensity indicates that a phased approach is appropriate, beginning with the low-input techniques that farmers are already willing to try and progressing to the knowledge-intensive techniques only as extension capacity is built.

The awareness figures reinforce this reading. Trap cropping attracted high adoption willingness despite low prior awareness, which suggests that the technique is perceived as feasible once explained and that the obstacle to its use has been exposure rather than acceptability. Hand picking and physical pest removal, by contrast, were widely known but attracted only moderate willingness, reflecting the labour burden they impose in a farming system already constrained by labour availability. The use of resistant crop varieties attracted substantial interest, contingent on reliable access to improved seed, which locates the constraint in the seed supply system rather than in farmer attitudes. Across the components, the analysis consistently distinguishes techniques whose adoption depends on training from those whose adoption depends on the provision of inputs or the building of extension capacity, a distinction that should govern the design of any scale-up programme.

Table 2. Farmer Awareness, Adoption Willingness and Resource Requirements for Individual IPM Components (n=350).

IPM Component	Awareness Among Farmers (%)	Willingness to Adopt (%)	Resource/Knowledge Requirement
Trap crops (e.g. cowpea border rows)	38.6	64.0	Low; accessible seed; farmer training needed
Mulching for moisture and weed control	54.3	58.0	Low; locally available materials
Hand picking and physical pest removal	71.4	47.0	Labour; time per hectare
Biological control (predatory insects)	12.3	38.0	Extension knowledge; identification skills
Timed pesticide application (threshold-based)	8.6	42.0	Extension knowledge; crop scouting skills
Use of resistant crop varieties	22.9	55.0	Improved seed supply; extension linkage
Neem extract pesticide (Azadirachta indica)	34.0	49.0	Preparation knowledge; tree access

5.4. Adoption Barriers

Focus group analyses identified lack of extension support as the most frequently cited adoption barrier, mentioned by 19 of 24 focus groups (79.2 per cent), followed by yield uncertainty (18 groups; 75.0 per cent) and perceived labour intensity of alternatives (14 groups; 58.3 per cent). Cost concerns were cited by 11 groups (45.8 per cent) and input supply gaps by 8 groups (33.3 per cent). These barriers are primarily institutional and logistical rather than inherent to the technologies themselves, suggesting they are amenable to programmatic intervention [4]. The centrality of extension support as a barrier underscores the finding from the regulatory study in this series that agrochemical management reform cannot succeed without substantial investment in extension service capacity [6].

The primacy of extension support as a barrier is consistent with the wider evidence from the study area, where farmers reported having never received formal training in agrochemical use and having relied instead on the informal guidance of local vendors. The same institutional vacuum that permits unsafe chemical practice to flourish also obstructs the adoption of safer alternatives, because in both cases the missing element is a competent, accessible source of technical advice that farmers trust. This symmetry is important for policy, because it means that investment in extension capacity would simultaneously advance the reduction of chemical misuse and the uptake of ecological alternatives, addressing both halves of the sustainability problem through a single institutional intervention rather than through separate and competing programmes.

The yield uncertainty barrier is equally consequential and closely linked to the collapse in adoption willingness observed when farmers were asked to consider a first-year yield reduction. Resource-poor farmers operating at or near subsistence cannot absorb a transitional decline in output, and their reluctance to gamble on unproven methods is a rational response to genuine food security risk rather than an expression of conservatism or ignorance. This has a direct implication for programme design, namely that alternatives must be demonstrated to preserve or improve productivity under local conditions before farmers can reasonably be asked to adopt them, and that the demonstration must occur on real farms in the study area rather than being asserted on the basis of results obtained elsewhere.

5.5. Preferred Extension Mechanisms

On-farm demonstration plots were the strongly preferred learning mechanism, cited by 86 per cent of respondents as their first preference, far ahead of organised group training (64 per cent) and radio programmes (48 per cent) (Figure 3). This preference reflects the experiential learning orientation of farming communities and the importance of demonstrated results on real farms under local conditions [20]. It also reflects the documented influence of farmer peer networks in technology adoption: seeing a respected neighbouring farmer achieve results is more persuasive than instructor-led training [14]. Programmes should prioritise establishing well-supported demonstration plots managed by respected farmers as the primary adoption catalyst.

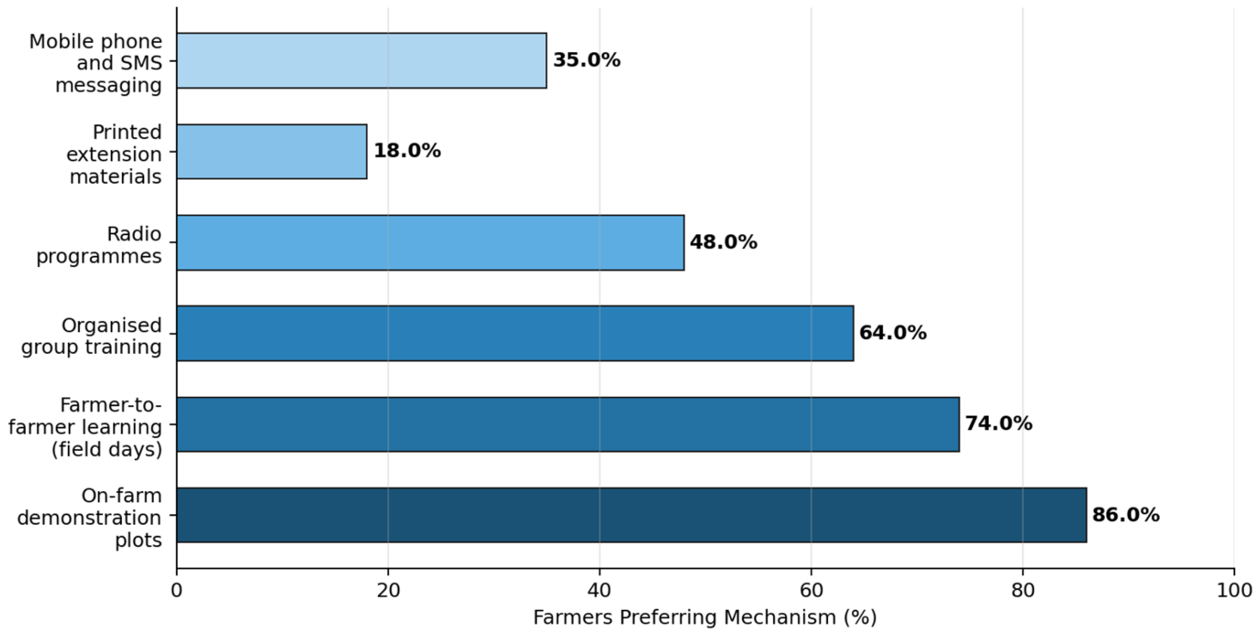

Figure 3. Preferred Extension Knowledge Transfer Mechanisms Among Farmers in Rivers Niger and Kaduna Catchments (n=350).

5.6. Farmer Characteristics and Adoption Intentions

Chi-square analyses revealed that younger farmers (below 40 years) showed significantly higher adoption interest than older farmers ($p=0.003$). Farmers with secondary education or above were more likely to express adoption willingness than those with primary education only ($p=0.011$). Farmers with prior extension programme experience showed higher adoption willingness across all alternatives ($p<0.001$). These associations indicate that targeting younger, more educated farmers and those with prior extension contact for initial demonstration and early adoption may generate multiplier effects through peer influence across the wider farming community [14].

5.7. Feasibility Synthesis and Prioritisation

Drawing the strands of the assessment together, the alternatives examined fall into three feasibility tiers that should govern the order of intervention. The first tier comprises the immediately deployable options, namely improved crop rotation, trap cropping and mulching, which build directly on existing farmer practice or knowledge, make light demands on external inputs, and attract high adoption willingness. These can be advanced at once through demonstration and training, with early results serving to build the credibility on which the adoption of more demanding techniques depends. The second tier comprises neem-based botanical pesticide and resistant crop varieties, both of which enjoy substantial farmer interest but are held back by specific and remediable constraints, respectively the absence of preparation knowledge and the unreliability of improved seed supply. These require targeted knowledge transfer and input-system strengthening but are otherwise well matched to local conditions.

The third tier comprises the knowledge-intensive techniques, biological control and threshold-based timed application, together with agroforestry and cover cropping, whose adoption is constrained either by the need for sustained specialist extension support or by concerns about land commitment and long return horizons. These should not be abandoned, but their promotion should follow rather than precede the establishment of extension capacity and the accumulation of farmer confidence through success with the first two tiers. This tiered sequencing respects the finding that farmers are willing to change only where productivity is protected and where the technical support to manage the change is genuinely available, and it avoids the common failure of promoting demanding techniques into an institutional vacuum where they cannot be sustained.

The synthesis also confirms that the binding constraints across all three tiers are institutional and logistical rather than inherent to the technologies. In every case the obstacle is some combination of absent extension support, unreliable input supply and the food security risk of transition, and in no case did farmers reject an alternative as unworkable in principle. This is an encouraging finding for policy, because institutional and logistical constraints are precisely those that a well-designed programme of extension investment, demonstration infrastructure and input-system development is equipped to remove. The pathway to reduced chemical dependence in the study area is therefore clear in principle, and its realisation depends less on agronomic innovation than on the political and financial commitment to rebuild the extension system that farmers repeatedly identified as the missing foundation.

6. Conclusions

Sustainable alternatives to synthetic agrochemicals are feasible for adoption in the farming communities of the Rivers Niger and Kaduna catchments, but their uptake requires investment in extension infrastructure that does not currently exist at adequate scale. IPM components, particularly trap cropping, mulching and resistant varieties, are the most immediately deployable alternatives given existing farmer knowledge and resource access. Improved crop rotation builds on existing practices and can be strengthened through relatively simple extension support. Neem-based botanical pesticides offer promising potential but require targeted preparation and knowledge transfer.

The following programme actions are recommended to translate adoption interest into practice: establishment of on-farm IPM demonstration plots in each agroecological zone, managed by respected farmer practitioners selected through community consultation [3]; training of trainers for State Agricultural Development Programme (ADP) extension agents in IPM, crop rotation and botanical pesticide preparation, with a minimum of one trained IPM-specialist agent per 500 farmers; organisation of quarterly farmer field days at demonstration sites to enable peer learning; development of a locally appropriate neem pesticide preparation protocol and input supply channel; and tracking of adoption rates and productivity outcomes over three cropping seasons to generate evidence for programme adjustment and policy advocacy [4].

These recommendations proceed from farmer-expressed priorities rather than external prescription, which materially improves their prospects of adoption. The strong and consistent preference for on-farm demonstration over classroom or broadcast instruction reflects the experiential learning orientation of the communities and the persuasive power of results achieved by a respected neighbour under local conditions. Programmes that honour this preference, by establishing well-supported demonstration plots managed by credible farmer practitioners and by convening regular field days at those sites, are therefore more likely to generate the peer-driven diffusion on which sustainable scale-up depends. The evidence that younger, more educated farmers and those with prior extension contact are the most receptive further indicates where initial effort should be concentrated in order to seed adoption and to establish the demonstration network from which wider diffusion can follow.

The transition to sustainable agrochemical management in the Rivers Niger and Kaduna catchments is both necessary and achievable, but it depends on a sustained institutional commitment that has so far been absent. The alternatives exist, farmers are willing to adopt them where productivity is protected, and the foundations of relevant practice are already present in the farming system. What is lacking is the extension capacity to transfer knowledge, the input systems to supply seed and materials, and the demonstration infrastructure to prove productivity equivalence under local conditions. Investment in these enabling conditions would advance the reduction of chemical contamination, the recovery of the catchment environment and the protection of the health and incomes of the farming communities, and it represents the single most consequential action available to government, extension services and regulatory agencies seeking a durable improvement in agrochemical management in the study area.

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