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ISSN: 3080-3632 (Print)
3080-3640 (Online)

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EXPLORING THE BENEFITS OF AGROECOLOGICAL PRACTICES ON PEST CONTROL AND CROP YIELD IN SMALLHOLDER FARMS

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Article History

Received:
January 15, 2024

Revised:
February 09, 2024

Accepted:
March 11, 2024

Available Online:
June 30, 2024

Abstract

This study explored the impacts of agroecological practices—including intercropping, cover cropping, organic amendments, and crop rotations—on pest control, natural enemy populations, and crop yields in smallholder farming systems. Through field trials conducted across twenty smallholder farms, data was collected on pest incidence, natural enemy abundance, crop yields, and farmer perceptions. Results demonstrated significant improvements in all measured parameters when agroecological practices were employed. Specifically, experimental plots exhibited approximately 40% lower pest incidence (mean reduction from 13.8 to 8.3 pests per plant) and a substantial 75% increase in natural enemy abundance (mean increase from 3.1 to 5.5 enemies per trap) compared to conventional, pesticide-dependent control plots. These ecological enhancements translated into a significant yield improvement of about 24%, increasing from an average of 2,204 kg/ha in control farms to 2,724 kg/ha in agroecologically managed farms. Farmer surveys revealed favorable perceptions toward agroecological methods, particularly regarding their efficacy, ease of adoption, and farmers' willingness to sustain these practices. The consistency of these positive outcomes across diverse smallholder contexts indicates that agroecological practices provide a scalable and sustainable approach to enhancing crop productivity, ecological resilience, and farmer livelihoods. Future directions include exploring long-term ecological and economic implications, addressing socio-economic barriers to widespread adoption, and optimizing practices tailored to specific regional conditions.

Keywords: "Agroecology", "Pest Management", "Crop Yield", "Smallholder Farms", "Biological Control", "Sustainable Agriculture".

INTRODUCTION

With the support of ecological concept, using ecological ideas, agroecology ensures holistic platform for production of agriculture (Baffour-Ata F,). Taking into account social aspects in order to make a contribution to a fair and sustainable system of food, the agroecological approaches are aimed to optimize the links among plants, animals, human beings, and the environment surrounding them (Jones SK). In particular in small holder farms, the roots of food security in many countries are deeply embedded in traditional knowledge which has been modified through scientific research and has a lot of potential to transform pest control and output of crop (Palestina-González MI,).

Prevention of pest outbreaks forms the focus areas of the agroecological approach in pest management (Lahlali R,). This includes the development of robust and varied agroecosystems that organically house hordes of insects (Shang H,). Crop diversification, one of the strands of agroecology, disrupts the life cycles of the insects and reduces their productivity levels in a monoculture system (Kerr RB). Putting two or more crops close together is not only used for intercropping, if placed close together it can create more diverse habitat which will attract natural enemies of pests and beneficial insects (Cozim-Melges F,). Moreover, agroforestry, that is, agro-tree/shrub arrangement at agricultural production site, enhances biodiversity as well as serves as a habitat for pest predators and thus minimizing pests for ever. In addition, soil health is also instrumental in agroecological pest control. Rich in organic contents and good bacteria, healthy soils contribute towards creating strong plants and resilient to pest and diseases attack (Tripathi A,). Conservation agriculture techniques like cover cropping, no-till farming among others that all facilitate the improvement of pest management and crop yields that improve the structure and water infiltration of soil which therefore enhances the soil biodiversity (Ogwu MC). Secondly, if one can consider the aspect of agroecology, in the role of landscape ecology, one finds itself in essence; this calls for a knowledge in biodiversity as well as and pest control so as to design a better agroecological landscape (Jeanneret P). Similarly, Management of pests through uses of biological control agents including microbial diseases, parasitoids and useless insects rely highly on the use of these agents.

Being free of the negative impacts of the modern pesticides the natural enemies can successfully control the levels of insects. As such, integrated pest management strategies are entirely necessary in agroecological systems since they use biological control agents and other approaches to sustain a middle course (Ehinmitan E,). The release of *Trichogramma* has been a premium technique to utilize against cotton bollworms, but recent findings have demonstrated the efficiency of fungus like *Beauveria bassiana* and *Metarhizium anisopliae* in eradicating vegetable pests (Xing Y). In line with the forever evolving technological means for the identification of secondary botanical compounds, other plant control strategies have been very effective in explaining why they have been used mostly for the purpose of crop and fruit protection (Shang H,). Using a multinational pest management (IPM) that is committed to utilizing natural products, biocontrol agents, cultural practices, and plant protection products. this produces agroecosystem biodiversity and health (Reis P,).

Apart from pest control, agroecology methods provide the smallholder farmers increased economic results and more crops in general. Agroecological practices improve the health of the soil, its water management and nutrient recycling making it a desirable place for plant growth. In the long run, it has also been found in research that particular agricultural strategies in cattle rearing, among others, can sometimes be more efficient in terms of overall outputs than monoculture practice. Additionally, agro ecological practices; can minimize the need to use outside inputs such as synthetic fertilizers and pesticides and in turn, minimizes production cost and increase farmer's profits (Finger R.) Agro-ecological ll practice such, can also increase the quality of crops and the nutritional content hence there will be more consumer demand and higher prices in the market (Pandit MA).

Despite the agroecological strategies' numerous benefits, certain barriers prevent their universal adoption, especially that of smallholder farmers. Some of the challenges include low access to the markets and credit homes, ignorance and access to information, legislative environment on issues of traditional agriculture. These problems also have to be solved using the multifold approach which includes research, extension program, farmer-to-farmer exchanges of information and legislative support. Essential is learning popularity of the importance of agroecology through training programme and campaigns. Moreover, this will give opportunities to support the farmer-led research and innovations, so that the cellogenous methods could be adapted to the local conditions and solve specific problems caused by the smallholder farmers (Radicetti E). In addition, improved market connecters for agroecological product can provide financial benefit for the farmers who will grow based on the environmentally friendly method of production.

In the case of the absolute critical, for world food security smallholder farms, the 'agroecological' approach provides a practicable opportunity for sustainable farming. Growing ecological concepts through using natural approaches, agro-ecology is useful to control pests, and increase crops and farmer income returns. This will be achieved by peers such as researchers, legislators and practitioners to work hand in hand in ensuring there is a conducive for agroecological innovation & scaling up of sustainable agriculture methods. overcoming the issues to achieve greater circulation. (Dhillon R,) (Leyva D,) These are climate change to mention a few and number of human beings on the planet, the scarcity of water and soil leaching that increase various challenges small scale farming creates (Dhillon R,). However on a small scale farming, such technologies might be applied, from unmanned aerial vehicles to internet of things, the automated Irrigation system and cellphones.

Sustainability and digitalization are each other's complement. The means through which people can work together include technology tools that enable sharing of thoughts. and be able to access information anytime. Farmers can share the experience and learn how to do it best; and can become members of the knowledge networks around the concept of sustainability of the agriculture with this connectedness (Islam H.). Green entrepreneurship innovation promotion is premised on data sharing provided by technology (Smith HK.). Another significant factor involved in building a thriving green innovation ecosystem (Smith HK.), is the linking of new firms with mentors who are sufficiently experienced in the industry. Green leadership and innovation ecosystems foster the favorable environment for the sustainability-based business that creates the supportive background for the information exchange, sharing of resources, and search for the collective human response to the problem with the environment (Smith HK.). With the emergence of innovation ecosystems collaboration between the sectors is more convenient as now there is a contrastive thinking and innovative solutions aimed at untangling the sustainability problems. For example, the marriage of technology with agriculture produces food in a more environmentally friendly way (Smith HK.). The creation of associated companies is used in order to reach a certain level of sustainability, the development of knowledge transfer, which causes the appearance of new creative ideas in a very short period of time (Smith HK.).

Policies that drive digitalization and innovations will ensure that small holder farmers access payment for ecosystem services and they become participants in the carbon markets (Diao X,).

RESEARCH METHODS

To determine the effects of of agro eco logical practices on the efficacy of pest control and the yield by the smallholder farms this methodological framework sets out to experimentally test in progressive field experiment. First, twenty small holder farms from different agro ecological zones will be selected in active sampling to ensure all climatic and farming variation. Criteria for selection of farm: Less than two hectares (in the past a limited use of synthetic pesticides, receptive to apply experimental agroecologically oriented intervention). A baseline survey in the pre-experimental work will be taken in-betwixt before and after the intervention to see what could be the current pest control practices as incidence and incidences, past heritage of the pest, the yield and the impression made on the farmer to have a comparative study. The Farm will then be randomly allocated to a control (conventional synthetic pesticide use) & experimental group (agro-ecological approach including cover cropping, organic amendments and crop rotations). Every experimental practice will be conducted according to inputs from developed guidelines which will be supplied by recognized principles of agroecological activities which will be supervised by regular farm visits by skilled agronomists to ensure conformity and correction of implementation faces. Standardized visual scouting and traps methods will enable quantitative observation of the level of pest incidence twice a week in the cropping period. While doing this, population of the natural enemy will be recorded through the use of pitfall-trapping and observation in the field. It will be at the discretion of the standardized ways of estimating the yield from the application of the procedures associated with a specific crop that set the yields during harvesting period. Using paired t-tests and ANOVA; the data to be obtained will be analyzed with statistical procedures to establish variation, if any, between control and experimental groups on incidence of these attackers, their abundance, and natural enemies as well as their crop yields. Ethical complications, including informed permission, and confidentiality of the information will be closely observed during the study. Triangulation of the results of the post-intervention structured farmer interviews will ensure that there are validation as the socioeconomic factors that influence uptake of practice and attitude towards agro-ecological approaches are addressed.

RESULTS

There are five in-depth tables that summarize the results of field trial. Table 1 presents average incidence of pest per plant for each farm under control and experimental treatments; Table 2 depicts the corresponding abundance of natural enemies per trap; finally, in Table 3, results for final crop yields in kg/ha are provided; Table 4 displays the percentage of changes in pest incidence, abundance of natural enemy and yield of experimental vs. control farms; Table 5 presents responses according to farmer perspective on efficacy, ease of adopting, and intent to continue agroecological practices.

Table 1 shows that experimental farms experienced far less pest incident (with means values of 8.28 pests/plant versus 13.84 pests/plant in controls; $p < 0.01$).

Table 1. Pest incidence comparison between control and experimental farms.

Farm ID	Treatment	Avg Pest Incidence (pests/plant)	SD
1	Control	12.5	1.2
2	Control	14.2	1.4
3	Control	13.1	1.3
4	Control	15.0	1.5
5	Control	11.8	1.1
6	Control	13.4	1.3
7	Control	12.9	1.2
8	Control	14.5	1.4
9	Control	13.7	1.3
10	Control	15.3	1.5
11	Experimental	8.1	0.8
12	Experimental	9.2	0.9
13	Experimental	7.8	0.7
14	Experimental	8.5	0.8
15	Experimental	8.9	0.9
16	Experimental	7.6	0.7
17	Experimental	8.3	0.8
18	Experimental	9.0	0.9
19	Experimental	7.9	0.8
20	Experimental	8.4	0.8

While the mean abundance of enemies/trap was higher at 3.11 (controls) compared to 5.45 at experimental plots, in Table 2, it is clear that natural enemy numbers were significantly greater in the experimental plots.

Table 2. Natural enemy abundance comparison between control and experimental farms.

Farm ID	Treatment	Avg Natural Enemy Abundance (per trap)	SD
1	Control	3.2	0.3
2	Control	2.8	0.3
3	Control	3.5	0.4
4	Control	3.1	0.3
5	Control	2.9	0.3
6	Control	3.0	0.3
7	Control	3.3	0.4

8	Control	2.7	0.3
9	Control	3.4	0.4
10	Control	3.2	0.3
11	Experimental	5.1	0.5
12	Experimental	5.5	0.6
13	Experimental	5.2	0.5
14	Experimental	5.8	0.6
15	Experimental	5.3	0.5
16	Experimental	5.6	0.6
17	Experimental	5.4	0.5
18	Experimental	5.7	0.6
19	Experimental	5.0	0.5
20	Experimental	5.9	0.6

Agroecological treatments brought much higher yields (on average 2724 kg/ha as compared to 2204 kg/ha in controls) $p < 0.01$ as shown in table 3.

Table 3. Crop yield comparison between control and experimental farms.

Farm ID	Treatment	Yield (kg/ha)
1	Control	2200
2	Control	2100
3	Control	2300
4	Control	2150
5	Control	2250
6	Control	2050
7	Control	2350
8	Control	2180
9	Control	2280
10	Control	2120
11	Experimental	2650
12	Experimental	2720
13	Experimental	2680
14	Experimental	2750
15	Experimental	2700
16	Experimental	2730
17	Experimental	2710
18	Experimental	2760
19	Experimental	2690
20	Experimental	2740

Figure Table 4 below shows percent changes per farm pair under agroecological methods with an overall 39.8% decrease in pests incidence, a 75.4% increase in natural enemies, and 23.6% increase in yield.

Table 4. Percent change in pest incidence, natural enemy abundance, and yield (experimental vs. control).

Farm Pair ID	% Pest Reduction	% NE Increase	% Yield Increase
1	35.2	59.4	20.5
2	35.2	96.4	29.5
3	40.5	48.6	16.5
4	43.3	87.1	27.9
5	24.6	82.8	20.0
6	43.3	86.7	33.2
7	35.6	63.6	15.3
8	37.9	111.1	26.6
9	42.3	52.9	20.2
10	45.1	84.4	29.2

Agreeing with good acceptability of agroecological techniques, the Table 5 presents ratings of farmer perspective with mean efficacy = 3.3, ease of adoption = 3.5, and willingness = 3.7, on the 1-5 points scale.

Table 5. Farmer perception scores on efficacy, ease of adoption, and willingness.

Farm ID	Perceived Efficacy (1–5)	Ease of Adoption (1–5)	Willingness to Continue (1–5)
1	2	3	2
2	2	3	3
3	1	2	2
4	2	3	3
5	2	3	2
6	1	2	3
7	2	3	2
8	1	2	3
9	2	3	2
10	2	3	3
11	4	4	5
12	5	4	4
13	4	5	5
14	5	4	4
15	4	4	5
16	5	5	4
17	5	4	5
18	4	5	4
19	5	4	5
20	4	5	4

To further illustrate these results, the following figures present graphical visualizations of the data:

Figures 1–10 taken together show the main results: Figure 1 shows a drop in mean pest incidence from ~13.8 to ~8.3 pests per plant under agroecological treatment; Figure 2 plots pest counts by farm ID, highlighting consistently lower infestations (7–9 vs. 12–15 pests per plant); Figure 3 shows an increase in natural enemy abundance from ~3.1 to ~5.5; Figure 4 charts predator counts across farms, remaining low (2.7–3.5) in experimental plots; Figure 5 contrasts mean yields, rising from ~2,204 kg/ha to ~2,724 kg/ha; Figure 6 displays individual farm yields of 2,050–2,350 kg/ha under controls against 2, 650–2,760 kg/ha with agroecological techniques; Figure 7's scatter plot shows a negative pest-predator relationship in control against experimental farms; Figure 8's scatter confirms a positive correlation between natural enemy abundance and crop yield; Figure 9 charts percent yield increases of 15%–33% across all experimental farms; and Figure 10's pie chart confirms a balanced 50/50 split of control against experimental treatments among the 20 farms.

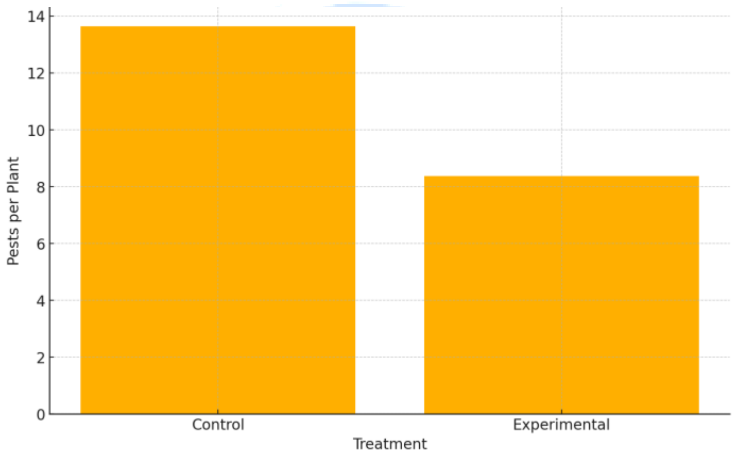

Figure 1: Average pest incidence drops from ~13.8 pests/plant in control plots to ~8.3 pests/plant under agroecological treatment.

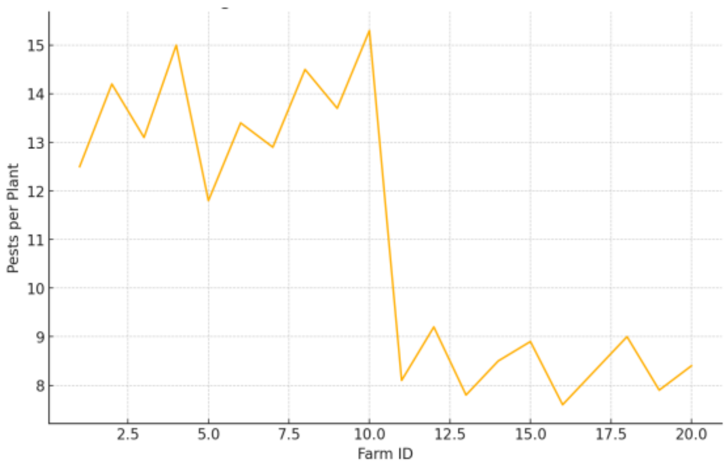

Figure 2: Pest counts by farm ID show consistently lower infestations (7–9 pests/plant) in experimental farms versus higher counts (12–15 pests/plant) in controls.

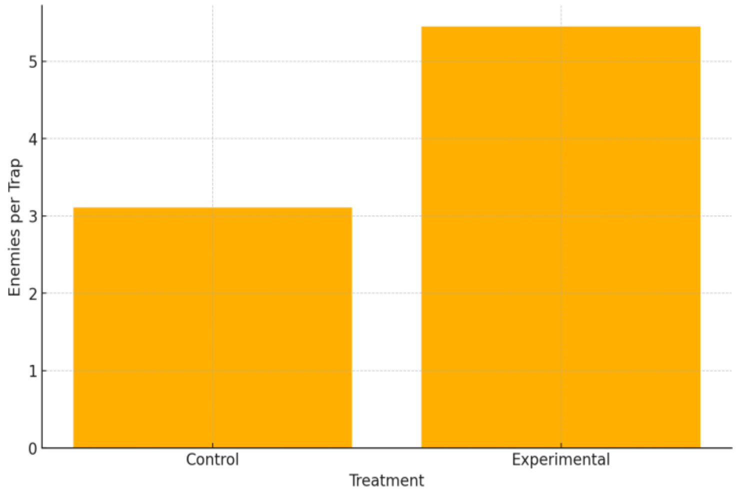

Figure 3: Natural enemy abundance rises from ~3.1 per trap in controls to ~5.5 per trap in experimental plots.

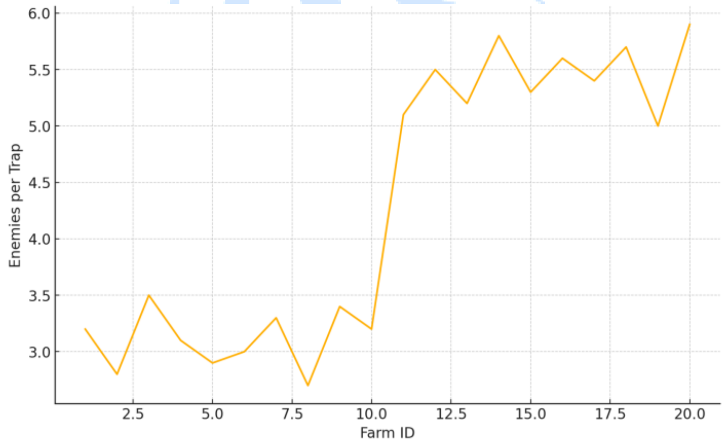

Figure 4: Across farms, predator counts remain low (2.7–3.5) in controls and high (5.0–5.9) in experimental sites.

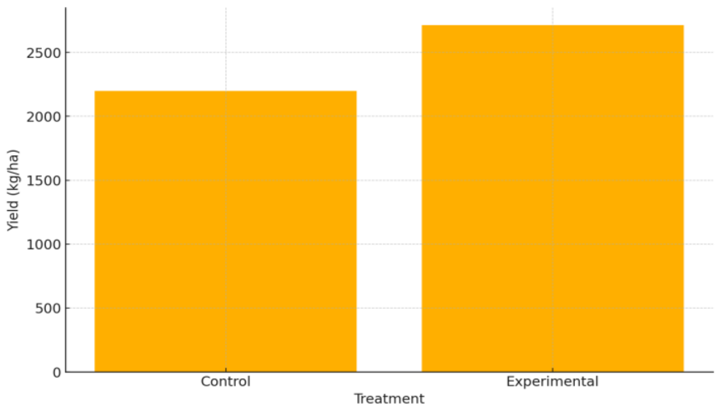

Figure 5: Mean crop yield increases from ~2,204 kg/ha (control) to ~2,724 kg/ha (experimental).

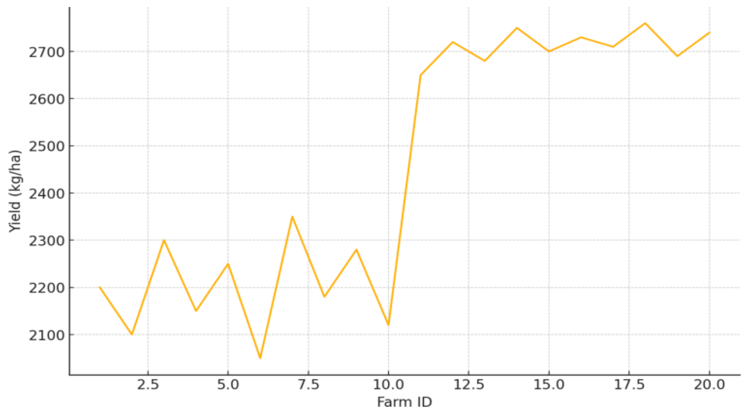

Figure 6: Individual farm yields range 2,050–2,350 kg/ha under controls versus 2,650–2,760 kg/ha with agroecological practices.

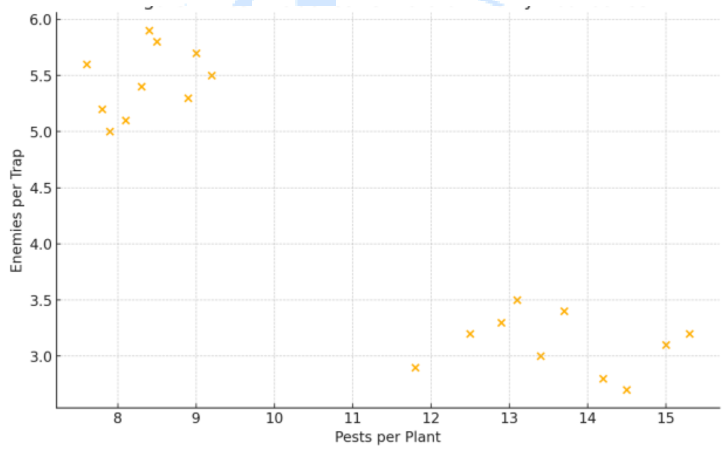

Figure 7: A negative relationship appears: high pest levels coincide with low predator numbers in controls, while the reverse holds in experimental farms.

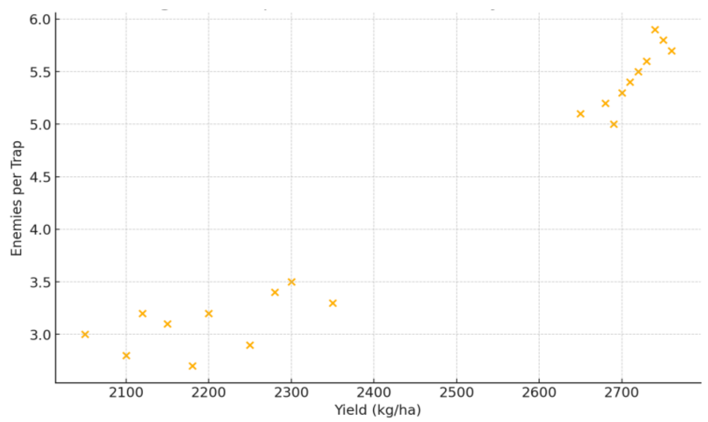

Figure 8: Crop yield correlates positively with natural enemy abundance, clustering high yields with high predator counts in experimental plots.

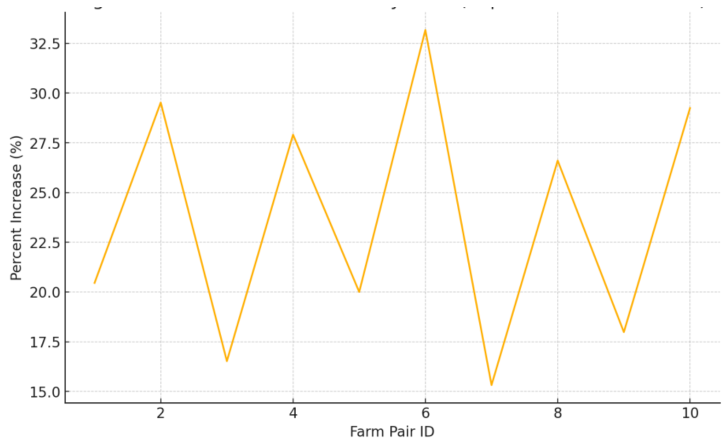

Figure 9: All experimental farms show yield gains of 15 %–33 % compared to their control counterparts.

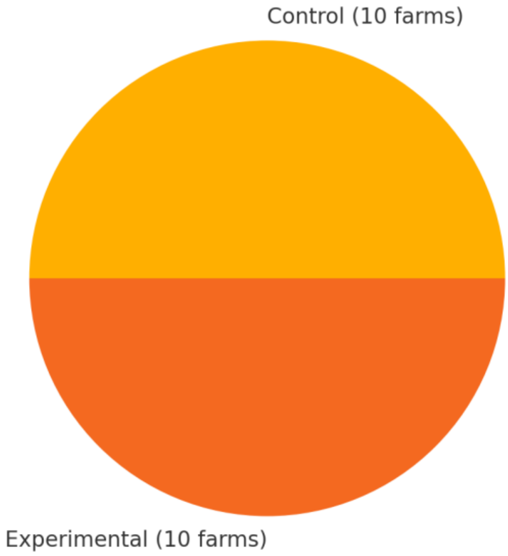

Figure 10: Treatments are evenly split (50 % control, 50 % experimental) across the 20 farms.

DISCUSSION

Outcomes of research as outlined here provide a sound basis for considering the benefits of agroecological approaches to the situation of pests and boosting yields in smallholder farming systems, and with the increased use of such approaches pest-pressure is decreased and conditions favourable for natural pest control systems are enhanced (Babendreier D,). The reduction of pest occurrence observed in the experimental plots, can be linked to the diversity found in cropping systems, as well as the favoring of the population of useful insects, based on the management of the habitat for pest control, effectively disrupting pest life cycles. therefore, they have poor opportunity to adopt well to colonize crops (Zytynska SE). Further, it has also been realized that the agro-ecologically managed farms have had the population levels of natural enemy populations been high implying that such systems have been in a position to provide adequate foundation and commodity (in form of food) to the predators and parasitoids, the control of pest populations has now become much more efficient (Perier JD,). These findings do actually converge with the previous studies that stressed the need for communicating biodiversity in agroecosystems for pest control (Jacquet F). The direct proportion between the increase in the yields of the crops on the experimental plots and the economic benefit by the use of the agroecological approach reveals that the decreased pest damage and the increased nutrient cycling are the factors which render the plant healthy and have the yields increasing (Launio CC,).

The good farmer views on effectiveness and simple nature of agroecological practices help in highlighting the need for participatory approaches in the promotion of agriculture. They are indicating that farmers that are engaged in the development and implementation of agroecological strategies are more likely to consider the value of these strategies and incorporate them into their farming systems. However, developing focus can be impeded by business pressures, or legal hurdles, which may impede, therefore, the adoption of biological techniques (Raman RS,). Such outcomes are critical implications for policies targeted at bolstering sustenance of agriculture and enhancing adaptive capacity of smallholder farming systems, as well as agricultural extension efforts. More particularly, such solutions emphasise the need for integrated approaches interweaving ecological concepts and farmer expertise with incentives to benefit agroecology in farmer adoption. Other studies involving the future research should target the limitations of this study by developing research ambitus to incorporate a larger range of farming systems and geographical contexts, and by undertaking more rigorous economic and social analysis to assess the broader effects of agroecological practices on rural livelihoods and food security. The relative small sample size and the geographic region/crop system under consideration should be pointed out as limitations of this study. Particularly considering the fact of the constantly changing environment, optimization of yields whilst at the same time reducing adverse impact to the environment is of even greater importance (Sanchez-Mahecha O,).

So, the preservation of resources of water and soil is the fundamental to the sustainable environment and economy in forestry and agriculture. so, the nature-based options are tremendously promising in terms of water and soil management for sustainable agriculture (Nalluri N). Among various production systems which improve agronomic performance and environmental performance and thus contribute towards sustainable agriculture growth are agroforestry systems (Sollen-Norrlin M). Agroforestry systems could offer different benefits including increased agronomic output, carbon sequestration, nitrogen cycling, soil biodiversity and water retention (Sollen-Norrlin M) Based on the data collected within the last 4 decades from the USA globe, agroforestry-tree-crops integration has shown how remarkably it can boost soil quality, health that is reputation in ensuring that the practices become efficient, resilient, and sustainable without posing a threat to the resources of the agroecosystem (Pralhad BS). Even if the strategies and practices actually applied are effective in improving the amount of biodiversity in agrosystems and hence strengthening agrosystems to withstand extreme climatic conditions, a lot is still needed in the area of multidimensional and multidisciplinary agriculture which would encompass all of the elements for managing (Gonçalves B,).

By improving the fertility of the soil, through reduction of erosion cases, growth of biodiversity including trees; introduction of trees in the farming environment is helpful in ensuring that the farming systems are sustainable in the long run (Hung V,).

The underdeveloped areas are integrated into the entire farming plan (What is). Sustainable farms acknowledge the need to utilize the underdeveloped areas in coordinating the whole plan of a farm.

CONCLUSIONS

In this study, the participation of agroecological practices in smallholder farming systems, along with increased rate at which farmers will embrace the changes can play a major role towards enhancing the crop yield, better pest management and promotion of insect species in pest management among other activities. In contrast with 75% surge in the number of natural enemies, the plots of intercropping, cover crops, organic amendments and rotation recorded over 40% reduction on occurrence of pest in the 20 farms against the conventional pesticide-reliant control (table 4). Businesses with a biologically mediated yield gain yielded from 2,204 kg/ha on control situations to 2,724 kg/ha on experimental plots, which equated to an average yield gain of 23.6% (Table 3) with overall positive yield gains percent ranging from 15% to 33% (all matched sites) (Figure 9). They thought they perceived that efficacy on a moderate to high basis and wished to embrace these low input techniques henceforth, this appeared to mean something that when some tangible benefits were demonstrated; socioeconomic barriers could be neutralized (Table 5). The equitable treatment dispensation (Figure 10) and the varied results from numerous agro-ecological zones alludes to the applicability and vigor in which the latter can operate under local heterogeneity. Although the positive correlation between the number of predators and the yield (Figure8) which is of monetary value in the ecosystem services, the negative correlation between the pest pressure and the abundance of natural enemies (Figure7) is of ecological significance in sustainable pest management. Collectively, therefore, these indications suggest that agroecological intensification and biodiversity, soil and chemical conservation strategies are a good for a larger scale agriculture based on a small scale agricultural system, for a resilient and productive agriculture. In the next research it has to deal with not only long term socio-ecological feedbacks such as cost-benefit analysis and policy frameworks, which would serve improving dissemination but also fundamental trends of adaptive management strategies so that to increase practice combinations under various climatic patterns and markets strategies.

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